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home with the two city cases. This subsequent development raises a question as to whether this was an instance of conveyance of infection by person or by place. The vicinity was heavily infested with rats and mosquitoes.

Starkville.—A family consisting of the father, mother, and six children under 10 years of age, in poor economic circumstances, moved on June 27, 1941, from Montgomery County, Ala., to a house in a very insanitary section of a cotton-mill village in an outskirt of Starkville. The baby boy, aged 10 months, developed upset stomach and diarrhea a few days before they arrived in Starkville. A day or two after his arrival in Starkville, he developed paralysis. He had what appeared to be in all respects a definite clinical case of poliomyelitis. A large number of children from all over the mill village, with a population of about 1,000, were in close contact with him and his brothers and sisters. Though a close watch was kept by the mill company doctor, and by the local health officer, not another case even remotely suggesting poliomyelitis developed among any of the other persons living in the mill village. The insanitary conditions and the association of many children with the afflicted child were comparable to the situation in the area worst affected in Cordova, Ala. Measles developed in all six of the children in the family with the case of poliomyelitis about 1 week after their arrival in Starkville. From them it spread widely throughout the mill village.

CONCLUSIONS

1. The findings from this study have epidemiological significance.
2. The preponderance of the epidemiological evidence is that in Mississippi in 1941 poliomyelitis infection was spread mainly not by personal contact but by unknown factors. These factors perhaps included rats, birds, domestic fowls, or bovines as harborage, and houseflies (*Musca domestica*), stable flies (*Stomoxys calcitrans*), blowflies, mosquitoes, fleas, or other insects as vectors, and tended to operate with striking localization. On the whole a picture was presented of spread of infection by place rather than by person.
3. Epidemiological studies of this kind on a large scale, covering different neighboring communities and also widely separated regions, combined with duly directed, coordinated, and concentrated laboratory research work, would go far, probably all the way, within a reasonable period of time, toward solution of the problem of the causation of poliomyelitis.

U.S. Pub. Health Rpts 57: 753-757 1942

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FIVE FUMIGANTS FOR DISINFESTATION OF BEDDING AND CLOTHING: A COMPARATIVE STUDY OF INSECTICIDAL PROPERTIES

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Fumigation has been defined as the process of liberating fumes or gases with the object of destroying insects, rats, mice, and other small animals acting as vectors of infection. In view of the present potentialities for the spread of disease during the congregation of military and civilian populations, it has seemed timely and appropriate to re-examine the properties of some of the principal fumigants and determine these properties under test conditions. It may be, too, that there will be an increasing need for the extensive use of fumigants in disinfesting fabrics and clothing coming into the United States from infected foreign territory.

In this study attention was directed to a consideration of the effectiveness of several fumigants when used to destroy insects in clothing and bedding. The chemicals chosen were those which have shown evidence of value as insecticides and have been used with reported success by public health workers.

Fumigants tested.—The fumigants tested were hydrocyanic acid, chloropicrin, methyl bromide, ethylene oxide-carbon dioxide mixture in the proportion of one part ethylene oxide to nine parts carbon dioxide, and ethylene dichloride-carbon tetrachloride mixture in the proportion of three parts ethylene dichloride to one part carbon tetrachloride.

Points considered.—In testing each of the fumigants the following points were observed:

1. Minimum lethal concentration (MLC) for insects and rats.
2. Penetration of fabrics.
3. Time exposure required for killing.
4. Safety features.
5. Effect upon fabrics.
6. Temperature as it affected insecticidal qualities.
7. Methods of application.

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Mechanical equipment.—The tests were conducted under laboratory conditions in a gas-tight steel chamber having a capacity of 11.637 cubic feet and provided with special inlets permitting the introduction of accurate quantities of the fumigant studied. Provision was made for obtaining a vacuum of 25 inches or more of mercury.

Experimental conditions.—In the tests for penetrating qualities, insects were placed between layers of blanket material folded in such manner that the gas would have to penetrate each separate layer before reaching the insects. The material was of a thin cotton-wool mixture averaging 16 layers to the inch when compressed by a pressure of ½ pound to the square inch of surface.

Vermin used.—The insects used in determining the efficiency of the fumigants were bedbugs (*Cimex lectularius*) and cockroaches (*Blattella germanica*). The wild rats were of the Norvegicus species. These particular vermin were chosen because of their reputed resistance to fumigants. In preliminary tests it was noted that bedbugs, in varying stages of development, exhibited no demonstrable difference in resistance when exposed to the fumigants. However, only those past the third molt were used. In the case of cockroaches the adults appeared to be more resistant than the young and for that reason only adults were used. A considerable variation in the resistance of individual bedbugs and cockroaches was noted, the greatest variation being found with hydrocyanic acid and the least with chloropicrin.

The results obtained in laboratory tests with the fumigants under stated conditions are shown in tables 1, 2, and 3.

TABLE 1.—*The minimum lethal concentration and the concentration for a 100 percent kill of bedbugs by each of five fumigants, in ounces per 1,000 cubic feet, under comparable conditions*

Fumigant	MLC for bedbugs in oz. per 1,000 cu. ft.			Hours of exposure	Fahrenheit temperature range	Concentration required for a 100 percent kill of bedbugs in oz. per 1,000 cu. ft.		
	Unprotected	Protected by 32 layers of blanket				Unprotected	Protected by 32 layers of blanket	
		Atmospheric pressure	25-inch vacuum				Atmospheric pressure	25-inch vacuum
Hydrocyanic acid	½	½	½	4	61° to 70°	2	4	[illegible]
Chloropicrin	3	4	4	4	65° to 72°	4	8	[illegible]
Methyl bromide	4	6	4	4	70° to 72°	6	8	[illegible]
Ethylene oxide mixture.	80 at 85°	128 at 85°	80	4	80° to 85°	192	256	[illegible]
Ethylene dichloride mixture.	88	102	128	4	70° to 75°	160	224	[illegible]

TABLE 2.—*The minimum lethal concentration and the concentration for a 100 percent kill of cockroaches by each of five fumigants, in ounces per 1,000 cubic feet, under comparable conditions*

Fumigant	MLC for cockroaches in oz. per 1,000 cu. ft.			Hours of exposure	Fahrenheit temperature range	Concentration required for a 100 percent kill of cockroaches in oz. per 1,000 cu. ft.		
	Unprotected	Protected by 32 layers of blanket				Unprotected	Protected by 32 layers of blanket	
		Atmospheric pressure	25-inch vacuum				Atmospheric pressure	25-inch vacuum
Hydrocyanic acid	½	½	½	4	60°	2	6	2
Chloropicrin	3	4	3	4	65° to 70°	5	6	6
Methyl bromide	3	6	3	4	66° to 72°	5	8	5
Ethylene oxide mixture.	80	128	80	4	70° to 85°	160	512	160
Ethylene dichloride mixture.	48	64	48	4	63° to 70°	68	160	88

TABLE 3.—*The minimum lethal concentration of 5 fumigants, in ounces per 1,000 cubic feet, for the destruction of wild rats, under comparable conditions*

Fumigant	MLC for rats in ounces per 1,000 cubic feet (unprotected)	Hours of exposure	Fahrenheit temperature range
Hydrocyanic acid	½	4	52° to 59°.
Chloropicrin	1	4	63°.
Methyl bromide	2	4	76° to 79°.
Ethylene oxide mixture	80	4	80°.
Ethylene dichloride mixture	55	4	73°.

To obtain the data shown in the tables, 139 tests were made. These ranged from a sublethal dosage with various conditions of exposure, temperature, and protection, to the maximum dosage necessary to produce a 100 percent kill. In comparing the fumigants the period of exposure to which the insects and rats were subjected was set at 4 hours, for preliminary tests had shown that the reduced toxicity of some of the fumigants (ethylene oxide and ethylene dichloride mixtures) when applied for less than 4 hours could not be compensated by a proportionate increase in concentration. Quick action is of prime importance and a fumigant which is not capable of producing satisfactory results within 4 hours will be of restricted value. To the limit of 12 hours the effectiveness of all the fumigants was found to be in direct proportion to the period of exposure. No tests were made beyond that exposure period.

A comparison of the five fumigants led to the following observations:

[illegible] minimum lethal dosage of each fumigant shows no marked difference [illegible] bedbugs and cockroaches. The exposure of wild rats was made because [illegible] that these animals would more nearly approximate human beings [illegible] in reaction to toxic gases. It will be noted that the greatest variation in the MLC between [illegible] insects tested was found in the case of chloropicrin. This is probably due to the irritating effect of the chloropicrin on the delicate lung tissue of rats, superimposed upon the purely toxic effect.

2. The tests indicated that the penetrating qualities of the fumigants followed very closely their molecular weights. Hydrocyanic acid and ethylene oxide-carbon dioxide mixture are the least penetrating to fabrics, having molecular weights of 27, 44, 44, respectively. All the fumigants penetrated 32 layers of thin blanket material composed of a mixture of cotton and wool in a 4-hour exposure at atmospheric pressure. Chloropicrin appeared to penetrate fabrics more readily than any of the other fumigants. When a vacuum was not used, time was the essential factor in the penetration of fabrics by all gases. When a vacuum of 25 inches or more was used, penetration of 32 blanket layers was accomplished by all the fumigants. In this connection a series of tests was made with chloropicrin, using a commercial steel fumigating chamber of 2,500 cubic feet capacity. A complete kill of both bedbugs and cockroaches was obtained within the center of a commercial bale of cotton, the concentration being 16 ounces per 1,000 cubic feet, with a 4-hour exposure and a 28-inch vacuum. Following a technique described in a United States Department of Agriculture publication,[1] the insects were placed in a hole drilled through the point of a long iron pin, which was then driven into the center of a bale of cotton by means of a sledge. Controls similarly placed but unexposed to gas were not injured.

3. *Toxicity.*—In proportion to its concentration, hydrocyanic acid appeared to be the most toxic of the fumigants tested, although the spread between the minimum lethal concentration needed to produce a 100 percent kill of bedbugs and cockroaches was very much greater than was found to be the case with the other fumigants tested. Chloropicrin and methyl bromide also gave a satisfactory kill within the 4-hour period of exposure. With ethylene oxide and ethylene dichloride mixtures a longer exposure was needed to obtain the full toxic effects under all conditions.

Delayed effects.—In observing the latent effect of the various fumigants on wild rats it was noted that when exposed to hydrocyanic acid they either died during or immediately after exposure or made a complete recovery, indicating that no delayed toxic effect resulted from exposure to the gas. With chloropicrin, when death of the animal did not occur during or immediately after exposure to a dosage approximating the MLC, symptoms of pulmonary irritation which lasted for several days were frequently observed. Rats recovering from such symptoms were observed for a period of 14 months during which period they appeared normal in all respects.

Following the exposure of rats to a MLC of methyl bromide, death was frequently delayed for a period of 1 to 3 days, with an occasional death much later. When recovery occurred, toxic symptoms persisted for a long time. Cockroaches and bedbugs exhibited the same delayed or prolonged toxic symptoms when subjected to a concentration of the gas considerably exceeding the MLC.

Rats exposed to ethylene oxide and ethylene dichloride mixtures in concentrations slightly less than the lethal dosage showed evidence of a delayed toxic effect by such symptoms as refusal to eat, inactivity, ruffed fur, unsteady gait, and a slow recovery extending over several weeks.

4. *Safety.*—Since the safety of a fumigant frequently depends upon the ease with which it can be detected by the human senses, this quality of the fumigants was closely observed. Chloropicrin was the outstanding gas in this respect, a concentration of one-sixteenth of the MLC being unbearable to humans because of its intense lachrymatory irritation. In its gaseous form this is believed to be the safest of all the fumigants tested, although the fumigator is subjected to the

[1] Technical Bulletin No. 63, U. S. Department of Agriculture.

hazard of severe skin burns when handling chloropicrin in liquid form unless protected by rubber gloves. The fumigant presents no explosive or fire hazards.

Methyl bromide, highly toxic in its effects, has only a slight odor suggesting bromine and it is very difficult to estimate the gaseous concentration by the sense of taste or smell. Rats exposed to sublethal concentrations of the gas frequently exhibited no symptoms during the period of exposure but evidenced toxic symptoms 24 hours later as shown by reduced activity and refusal to eat. No irritation to the eyes was noted in minimum lethal concentrations. For these reasons it is considered particularly dangerous.

Neither ethylene oxide mixture nor ethylene dichloride mixture has sufficient warning qualities by which it may be readily detected by other than experienced fumigators. Frequent exposure of fumigators to sublethal concentration of these gases during the process of aeration may produce a cumulative toxic effect.

5. *Effect on fabrics.*—None of the fumigants in gaseous form were found to affect the color or texture of fabrics or noticeably to corrode metals. Samples of various textiles of both vegetable and animal origin were subjected to large quantities of the fumigants in gaseous form without any deterioration being noted.

6. *Temperature.*—A low temperature was found to alter materially the efficiency of two of the fumigants, ethylene oxide and ethylene dichloride mixtures. For these fumigants a temperature of 80° F. or more was required to obtain a maximum result, although fair results could be obtained at temperatures as low as 65° F. Below the latter temperature ethylene oxide mixture was unsatisfactory. Ethylene dichloride mixture was found effective as low as 57° F. with only a moderate increase of dosage.

7. All of the fumigants mentioned may be obtained commercially in liquid form in steel cylinders from which they may be sprayed into fumigating chambers or compartments, under their own pressure or that of compressed air. With hydrocyanic acid and chloropicrin this method may be altered by distributing, from sealed cans, impregnated absorbent disks containing the liquid gas. These cans are light in weight, easily opened, and contain from 1 to 4 pounds of liquid gas, each disk representing about ½ ounce.

The application of methyl bromide and ethylene oxide and ethylene dichloride mixtures requires the transportation and use of heavy, cumbersome steel containers equipped with pressure gages, gas-tight valves, sprays, hose, etc., together with scales for weighing proper quantities for small chambers or compartments. With hydrocyanic acid and chloropicrin all this equipment may be dispensed with by the use of can type containers, thus resolving the problem into one of comparatively easy transportation and simple application.

When the transportation of heavy apparatus or explosive gas presents a major problem in the disinfestation of bedding and clothing of the civil population or of the armed forces, it would appear that chloropicrin is the fumigant of choice. The exercise of a little ingenuity in converting small empty buildings, packing boxes, trash cans, tents, canvas bags, etc., into fumigating devices should permit the use of chloropicrin as a disinfestation agent under conditions which might otherwise be considered adverse.

CONCLUSIONS

The choice of a fumigant will depend upon location, time, space, equipment, transportation, quality, quantity, use to which the fumigated material is put, presence of trained operators, safety features, and the kind of insects to be eradicated. When so many factors must be taken into consideration, a comparison of the value of the

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fumigants tested is difficult and the results may vary somewhat according to individual judgment.

None of the fumigants tested were found to be ideal in every respect, and *no single fumigant was superior under all conditions.* However, in connection with bedding, clothing, and like textiles, it is believed that hydrocyanic acid and chloropicrin are the fumigants of choice. As an insecticide, chloropicrin appeared to have the most desirable qualities. It is nonexplosive and has excellent warning characteristics in sublethal concentration. Rats exposed to slightly less than lethal concentration for a period of 4 hours show no evidence of permanent pathology. The objection to this gas is mostly concerned with the necessity for ventilation following *fumigation. It clings* persistently to fabrics, requiring either prolonged aeration, agitation, heating, mechanical ventilation, or some combination of these factors. Unless used in an isolated building, its irritating properties necessitate an exhaust extending above the surrounding buildings. None of these objections are so serious as not to be easily overcome in a commercial fumigating vault located in large centers of population or by isolating the fumigation chamber in field disinfestation of bedding and clothing.

It would appear that chloropicrin has considerable possibilities as a delousing agent for clothing especially when war conditions require such treatment on a large scale and when suitable apparatus for the application of steam heat is not available. Moore[2] and Moore and Herschfelder[3] report the destruction of both lice and eggs in 30-minute exposures using a concentration of 4 cc. to a cubic foot of space. The same results should be obtainable by greatly reduced concentration if the exposure were increased to a 4-hour period. The writer was able to obtain satisfactory kill of the eggs of bedbugs in a concentration of 12 ounces per 1,000 cubic feet of space with a 4-hour exposure.

From a toxic standpoint, methyl bromide is an excellent fumigant for bedbugs and cockroaches. It is nonexplosive and presents no fire hazard but shows evidence of a delayed toxic effect in sublethal concentration. It is not readily detected by the senses of smell and taste. In comparatively weak concentration a toxic quantity may be inhaled without the victim being aware of exposure.

Ethylene oxide-carbon dioxide mixture proved *effective as an insecticide* when the test subjects were exposed to the full concentration of gas, but is somewhat deficient in penetrating qualities and requires prolonged exposure to produce results.

In comparing the relative toxicity of the ethylene oxide and ethylene dichloride mixtures, the kind of insects tested must be considered. A small percentage of both bedbugs and cockroaches proved to be extremely resistant to ethylene oxide mixture, necessitating a high concentration of the gas in order to secure a 100 percent kill. On the other hand, a small percentage of bedbugs appeared quite susceptible to this gas. For cockroaches ethylene dichloride mixture appeared definitely more toxic than the ethylene oxide mixture. At temperatures below 65° F. the ethylene dichloride mixture was more effective than the ethylene oxide mixture. The low toxicity of both these gases coupled with the high concentration necessary in order to obtain a satisfactory kill of *insects are* undesirable features when large quantities of bedding and upholstery are to be fumigated.

[2] Moore, Wm.: J. Lab. and Clin. Med., 3:261-268 (1918).
[3] Moore, Wm., and Herschfelder, A. D.: Univ. of Minn. Research Pub., Vol. 8, No. 4, July 1919 (86 pages).

No new data relative to the value of hydrocyanic acid gas were developed by these tests. In the absence of a vacuum this gas did not penetrate fabrics quite as readily as chloropicrin or methyl bromide. The absence of definite warning qualities in *lethal concentrations* renders it dangerous to life when used by inexperienced persons. However, its high toxicity, rapid evolution from a liquid to a gaseous state, coupled with the fact that the gas approximates the weight of air and thereby promotes rapid diffusion, makes it a valuable fumigant for eradicating rodents and insects from buildings and their furnishings.

Tests other than those mentioned indicate that in the case of hydrocyanic acid the residue gas remaining in fabrics following *fumigation* is much *greater than formerly* believed. Absorption and adsorption appear to play an important role in the ability of a fumigant to penetrate fabrics.

It is suggested that in addition to the processes of absorption and adsorption there may be a reverse chemical reaction between certain gaseous fumigants and fabrics derived from both animal and vegetable fibres, which may account for a portion of retained gas.

ACKNOWLEDGMENTS

The author desires to acknowledge his appreciation to Dr. Robert Olesen, chief quarantine officer at the Port of New York, for advice and suggestions in the preparation of this article and to Administrative Assistant John J. Essex, of the United States Public Health Service, for assistance in completing the tests which are the basis of this report.

PREVALENCE OF COMMUNICABLE DISEASES IN THE UNITED STATES

March 29–April 25, 1942

The accompanying table summarizes the prevalence of nine important communicable diseases, based on weekly *telegraphic* reports from State health departments. The *reports from* each State are published in the PUBLIC HEALTH REPORTS under the section "Preva-

EDB
Quarantine Control
Insects
Carbon Tetrachloride

(52)

Fumigants for Quarantine Control of the Adult Brown Dog Tick:[1] Laboratory Studies[2,3]

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ABSTRACT

Small-scale laboratory fumigations in 1972 indicated that comparatively high dosage schedules of methyl bromide applied at both normal atmospheric pressure (NAP) and at a reduced pressure of 105–110 mm Hg were required to provide quarantine control (100% mortality) of *Rhipicephalus sanguineus* (Latreille). At NAP, 64 mg/liter for 3.5 h at 22.2°C and 96 mg for 5.5–6 h at 11.1° gave control. Sulfuryl fluoride 16–32 mg/liter for 16–24 h and ethylene oxide-carbon dioxide (1:9) mixture 160 mg/liter for 16–24 h also appeared effective at NAP. Ethylene dibromide 16 mg/liter for 2 h and aluminum phosphide 52.17 pellets/m³ for 72 h were ineffective at 22.2°. Saturated atmosphere of carbon tetrachloride was effective even with an exposure as short as 1.5 h at near 22°C. Fumigation below 10°C does not appear practical for the fumigants tested because of the high dosages required.

Ticks occasionally are intercepted on or with various commodities in commerce. Practical methods of quarantine control (100% mortality) for ticks of medical or quarantine importance are needed to provide minimum damage with least interference to trade.

Little or no information is available regarding efficiency of various fumigants against ticks. Barnett and Parsons (1963) reported that methyl bromide (MeBr) 35.6 mg/liter for 24 h at 21°C or above at normal atmospheric pressure (NAP) killed small numbers of adult ticks of *Rhipicephalus appendiculatus* Neumann, *R. evertsi* Neumann, and *Amblyomma variegatum* (F.); nymphal stages of *R. appendiculatus*, *A. variegatum*, and *Ornithodorus moubata* Murray; and larval stages of *R. appendiculatus and Boophilus decoloratus* (Koch) in the center of bales of hay. Eggs of *B. decoloratus* failed to hatch after a 4-h exposure. Some adults of *R. appendiculatus* were live and fully active 24 h after exposure to 17.8 mg/liter for 24 h. While some larvae of *B. decoloratus* and adults of *A. variegatum* were live but incapable of active movement immediately after exposure, they were dead the next day. Reported here are results of laboratory tests in 1972 with various fumigants against adults of the brown dog tick, *R. sanguineus* (Latreille).

MATERIALS AND METHODS.—With the cooperation of Livestock Insects Investigations, Agric. Res. Serv, USDA, Kerrville, TX, 200 engorged adults of the brown dog tick were received weekly for 26 weeks by air mail. Upon receipt, the caged ticks were held for 4–28 h at near 5.6°C. The ticks were divided randomly into lots of ca. 20 each and placed in perforated pill boxes. The ticks were normally held for 48 h or more at treatment temperature before fumigation, and afterward they were held at treatment temperature for examination the next morning, usually 16–24 h. Survival was considered as the ability to walk. Survivors were examined later to determine if delayed mortality occurred.

Fumigations were made in 210- or 230-liter fumigation drums at NAP, or in a 19.1-liter vacuum chamber at a sustained reduced pressure of 105–110 mm Hg situated in a controlled-temperature (± 0.8°C) room. Sulfuryl fluoride (Vikane®[4]) or ethylene oxide (EO)-CO_2 10:90 mixture (Carboxide®[5]) were added to the drum until the desired experimental concentration was obtained as determined by thermal-conductivity (TC) analyzers; for these 2 fumigants only, the ticks were placed in the drum through a small stoppered opening. MeBr was measured in a glass dispenser calibrated in 0.2-ml divisions. Aluminum phosphide (Phostoxin®[6]) pellets were placed on a metal pan in a drum containing damp toweling to provide humidity. Ethylene dibromide (EDB) was measured from a burette calibrated in 0.01-ml divisions into a stainless steel cup. The cup was heated 3–5 min on a 110-w ring to insure vaporization of the EDB. Excess of CCl_4 was added to a 1-quart jar, so that after sealing, the atmosphere in the jar eventually would become saturated (ca. 896 mg/liter). Fan circulation 2–3 changes/min for 10–15 min was used for all NAP fumigations, except that it was continuous with EDB and none with Phostoxin and CCl_4. Circulation was also continuous in fumigations at reduced pressure.

Concentrations of MeBr, Vikane, and Carboxide were determined with TC analyzers at the beginning and end of the exposure, except that with reduced pressure the reading was made 5–10 min before the end of exposure following release to NAP. Concentration of EO in the mixture was determined by use of a soda asbestos filter (Ascarite®) (Heseltine 1961). Concentrations of phosphine from Phostoxin were determined with Drager or Kitagawa detector tubes.

RESULTS AND DISCUSSION.—Because of little or no evidence of sex difference in survival, data for both sexes were combined. However, survival when present was usually of the larger individuals.

MeBr was effective at all temperature ranges above 10°C. Below 10°C (i.e.,near 5.6°) the results were erratic, and the dosage schedules apparently required were not considered practical except for emergency use. At NAP (Table 1), dosage of 64 mg/liter for 3.5 h appeared effective at 22.2°C. Survival occurred with a concentration-time (CT) product (Milligram per liter × hour) of 158. At 11.1°C survival occurred at a CT of 324, and 2 adults were moribund for 1–2 days at a CT of 465.

[1] Acarina: Ixodidae.
[2] Received for publication Apr. 16, 1973.
[3] Mention of a proprietary product does not necessarily imply endorsement by the USDA.
[4] Vikane furnished by Dow Chemical Co., Midland, MI.
[5] Carboxide furnished by Union Carbide Corp., New York.
[6] Phostoxin furnished by Hollywood Termite Corp., Alhambra, CA.

Table 1.—Efficiency of methyl bromide in atmospheric fumigations against adult brown dog tick. Initial observation morning after end of exposure.

°C	Dosage mg/liter	Exposure h	CT mg×h	Tests no.	No. Ticks Live[a]	Moribund	Dead
33.9	32	2	56	1		1[b]	20
	40	2	66.5–75	4	1		90
	44	2	79.5	1		1[b]	21
	48	2	85–87.5	3		1[b]	56
		2.3–3	100–129	4			88
27.8	48	2.5	103.5	1	4	1	9
		2.75	106–116.5	4		4[c]	80
		3	109–129	5		1[c]	99
22.2	32	2	55	1	18		
	48	3	120	1	2		19
		4	158	1	2		21
	54	3.5	164.5	1			21
	64	3.5	175–200	8			152
		4	204–229	2			40
11.1	80	5	352	1	1		21
	96	4	324	1	1		18
		4.5	368–389	2		2[c]	38
		5	412–465	4		4[c]	81
		5.5	473	1			18
		6	518	1			19
5.6	54	2	78	1	19		2
	64	4	213	1	15		6
	72	16	864	1	3		22
	80	5	340	1	2		1
		5.5	423–452	2	4		20
		6	408–486	6	6	2[c]	119
	104	6	540–564	2	4	1	35
	112	7–7.25	679–703	2	2	2	51
	128	7	738–784	2	2	1	62
		8	836–964	4		6	89
	136	8	876–984	5			111
	144	8	1016	1			36

[a] One or more live at 1 week.
[b] Dead at 2 days.
[c] Moribund at 1 and 2 days, dead at 3 days.

Table 2.—Efficiency of methyl bromide at reduced pressure against adult brown dog ticks. Initial observation morning after end of exposure.

°C	Dosage mg/liter	Exposure h	CT mg×h	Tests no.	No. Ticks Live[a]	Moribund	Dead
			360 mm Hg				
22.2	32	2	56	1	1	1	17
	48	2	80	1	3	1	17
			105–110 mm Hg				
27.8	36	2	62–63	3			41
	40	2	63–69	5		1[b]	91
	44	2	76	1			18
	48	2	86.5	1			17
22.2	40	2	66	1			11
	48	2.25	89	1	1	1	18
		2.5	100–105	2		2[b]	44
		2.75	110.5–121	5			112
16.7	48	3	120–132	2		2[b]	36
	54	3	156	1			21
	64	3–4	170–228	3			56
11.1	48	4	174	1	4		22
	64	4	228	1	2[c]	2	19
	72	4	257–290	4	4	9[c]	81
	80	4	310–342	2		3[c]	31

[a] One or more live at 1 week.
[b] Dead at 2 days.
[c] Dead at 3 days.

Table 3.—Efficiency of sulfuryl fluoride in atmospheric fumigations against adult brown dog tick. Initial observation morning after end of exposure.

°C	Dosage mg/liter	Exposure h	CT (mg×h)	Tests no.	No. Ticks		
					Live[a]	Moribund	Dead
22.2	10.6	16	186	1			24
	18.1	16	573.5	1			22
	32	24	658.5	1			22
16.7	14.2–16	16	212.5–240	2		1[b]	36
	15–16	24–31	348–466	2			38
11.1	15.9	16–20	241–301	2		7[b]	40
	16	24	372	1			19
	31.9–66	16–24	503–1497	10			208
5.6	11.5	20	220	1	1	8[c]	10
	31.9	16	496	1	1		20
	45.1	16	708		1		22
	17.7–35.4	16	262–489	5		2[d]	99
	12.4–26.8	20	221–574	7		2[c]	141
	12.4–35.4	24	297–722	6		1[d]	117
	48.6–53.1	24	1104–1232	2			40

[a] Live at 1 week.
[b] Moribund at 4–6 h, dead next morning.
[c] Dead at 4 days, no observations at 2 or 3 days.
[d] Dead at 2 days.

Limited tests indicated that a schedule of 96 mg for 5.5–6 h appeared satisfactory with a CT of 473 or above. Somewhat lower dosages and exposures are required to kill the ticks at reduced pressure (Table 2). The tolerance of most plant commodities to the MeBr schedules required for control of these adult ticks is questionable, especially at the lower temperature ranges.

Sulfuryl fluoride 16–24 h exposure at NAP appeared effective at temperatures above 10°C (Table 3). At 5.6°C variable results were obtained. Survival occurred in a 16-h exposure with a CT of 708, but in repeated tests with a 24-h exposure using lower CT's, complete mortality was obtained.

The EO mixture appeared effective at all temperatures, even with an exposure of less than 24 h (Table 4). The only survival (including those moribund) occurred in a 6-h exposure at 5.6°C with the comparative low dosage of 232 mg/liter of the mixture (CT of the EO in the mixture was 114).

In tests with other fumigants, CCl_4: was effective in exposures of 1.5 h or more. With a 1-h exposure, a few ticks were moribund for several days before dying. EDB 16 mg/liter for 2 h at ca. 23°C was not effective. Aluminum phosphide 12 pellets/230 liter (52.17 pellets/m^3) for 72 h at 22.2° also was ineffective. Higher dosages of of these 2 last-mentioned fumigants are not considered practical.

In limited tests, adults held 7 or more days at near 5.6°C pretreatment were more tolerant to MeBr than those held 24–48 h following transfer from 22°C. Although no tests were made, it is considered that raising the temperature of a commodity infested with ticks to permit use of a lower dosage schedule, or to obtain a commodity temperature at which treatment is author-

Table 4.—Efficiency of ethylene oxide: carbon dioxide-10:90 mixture in atmospheric fumigations of adult brown dog tick. Initial observation morning after end of exposure.[a]

°C	Dosage[a] mg/liter	Exposure h	CT[b]	Tests no.	No. Ticks		
					Live[c]	Moribund	Dead
22.2	131	4	59	1			26
	146–184	6	73–78	4			78
	168–240	16	192–352	2			43
11.1	162–194	4	48–58	2			30
	162	6	70.5	1			21
	170	16–24	100–220	2			36
5.6	179	4	62	1			21
	176–232	6	84–114	2	2	1[d]	36
	126.5–173	16	136–320	8			171
	262.5	8	252	1			20

[a] Dosage of mixture as determined from initial TC reading.
[b] Average concentration of ethylene oxide (milligram per liter) as determined by TC readings at beginning and end of exposure times time in hours.
[c] Live at 1 week.
[d] Dead by afternoon.

Fumigant	Temp. C°	Dosage mg/liter	Exposure h	Minimum concn at h	
				0.5	end
MeBr at NAP	32.2 or above	64	3	55	45
	26.7–31.7	80	3	65	52
	21.1–26.1	96	4	75	50
	15.6–20.6	112	5	88	60
	10.0–15.0	128	7	100	70
At reduced pressure	26.7 or above	48	2.5		
	21.1–26.1	48	3.5		
		54	3		
	15.6–20.6	64	4		
	10.0–15.0	88	5		
EO-CO[5] mixture	21.1 or above	320	16		
	10.0–20.6	320	24		
Sulfuryl fluoride	21.1 or above	32	24		20
	10.0–20.6	40	24		24

ized or recommended, could result in survival, because the physiological temperature of the ticks was not raised immediately. This could be an important factor in the fumigation of other pests of quarantine interest.

The above schedules were recommended to the Program for fumigation of commodities infested with ticks. Because of the limited number of ticks tested, and with little or no data available on other species or stages, the schedules of necessity are higher than those indicated to provide control.

For the EO-CO_2 mixture the minimums are a reading of 145 at 2–4 h and of 135 at the end of exposure, on a TC analyzer calibrated for the mixture and when 1% of scale equals 2 mg MeBr.

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8

U.S. War Dept. T.B. Med 184: 3-5 1945
"Disinfestation Procedures"

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MB
Clothes
method of Application

and inner folds of clothing and bedding, are to be treated. Shaking or beating of bagged or stacked textiles will assist even distribution of the powder. For complete disinfestation by this method, time must be allowed for the lice to crawl about and expose themselves to the powder. A minimum of 24 hours after exposure is required to insure death of lice. Eggs are not destroyed by this method, and the louse powder must remain in the clothing, bedding, and equipment for about 10 days, or until all eggs have hatched, so as to kill the newly hatched nymphs.

* (2) *Fumigation with methyl bromide.* (*a*) *General.* Methyl bromide is a colorless, odorless, volatile liquid, boiling at 40° F. to produce a gas which is highly effective in destroying all forms of insect life. This gas is three and one-half times as heavy as air, but diffuses readily, and, when thoroughly mixed with air, does not settle rapidly. It has unusual properties of penetration and is effective at much lower temperatures than most fumigants. Its effectiveness is not decreased by the presence of moisture, unless sufficient water is present to form a film which prevents penetration. In its gaseous state the use of methyl bromide is usually limited to fumigation within tight enclosures. When properly employed it kills lice and their eggs after relatively short exposure periods. Exposure to methyl bromide makes lice more active and they may be seen wandering about the clothing immediately after fumigation. However, these lice are unable to feed or lay viable eggs and they will soon die. Methyl bromide does not injure or shrink fabrics or leather, is not corrosive to metals, and will not damage other items such as musical instruments, watches, and cameras. However, it has occasionally been reported to cause offensive odors from sponge rubber. No sorting of clothing or equipment, with separate treatment of each type, is required when deloused by this method.

(*b*) *Precautions.* High concentrations of methyl bromide are dangerous to man. Exposure to low concentrations for short periods of time will not cause serious disturbance, but should not be continued beyond certain limits. Harmful concentrations of methyl bromide may be determined with the halide leak detector (Frigidaire Leak Detector, Piece SA-2136, or equal) by noting the color changes in an alcohol flame. This leak detector consists of an alcohol torch which heats a copper coil and a sampler tube which picks up air and supplies it to the flame. The tube must be kept clean, since particles of lint or dust will interfere with the test. The torch is adjusted to give a strong colorless flame which brings the copper coil to a red heat. In the present of methyl bromide (or other halide) the flame becomes green or blue as indicated in the following table:

Flame color	Parts methyl bromide (per million by volume)	Pounds methyl bromide (per thousand cubic feet)
Almost invisible	0	0
Rather faint green	40	0.010
Moderate green	60–100	.014–.024
Strong green; slightly blue at edges	130	.031
Strong green; rather blue	180	.043
Strong blue-green	240–360	.058–.086
Strong blue	800	.192

Warm blooded animals can survive high concentrations for brief periods, but prolonged exposures to low concentrations may be injurious or even lethal. Based on observations of its effect on animals, it is believed that accidental exposure to the concentrations of methyl bromide ordinarily used in fumigation is not likely to cause injury. However, working many hours in a relatively low concentration may be harmful. The maximum concentration allowable within fumigation plants should not exceed 30 parts per million. The air about the fumigation vaults and in the areas where fumigated clothing is handled should be tested frequently to assure safety. If directions are carefully followed, the entire procedure of fumigation for delousing clothing can be done safely without the wearing of gas masks by operating personnel.

(*c*) *Methods. 1. Vault fumigation.* (a) *Equipment and supplies.* The vault provided for the fumigation of clothing and other equipment consists of a gas-tight chamber with means for introducing and circulating methyl bromide. The amount of methyl bromide used will depend on the temperature of the clothing or other material which is fumigated. When temperature is 60° F. or over, the dose is 3 pounds per standard vault (about 330 cubic feet), or at the rate of 9 pounds per thousand cubic

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feet. For all temperatures below 60° F. use 4 pounds methyl bromide in the standard vault, or at the rate of 12 pounds per thousand cubic feet. The duration of exposure to the full concentration of the gas is 30 minutes, regardless of temperature. Methyl bromide in 1-pound cans is requisitioned from the quartermaster as stock No. 51-M-892.

(b) *Procedure.* The men to be deloused bring with them for disinfestation all items of individual clothing and equipment, including barrack bags, and proceed as in steps 1, 2, and 9, below, while fumigation personnel ordinarily carry out steps 3 to 8 inclusive:

(*1*) Each man undresses, places all clothing and equipment, including that worn, in the barrack bag, closes it, and marks it for identification. Everything, including shoes, helmet, and valuables, must be disinfested.

(*2*) After depositing the closed barrack bags at a designated point, the men proceed with personal disinfestation as described in *a* (2) (*b*) above.

(*3*) Load the fumigation vault with bags on tiers of removable shelving. If trucks are provided, load bags onto the trucks and then wheel into the vault.

(*4*) Close tightly the vault door and all openings, and set the damper to "circulate."

(*5*) Start the circulating fan or blower and introduce the required amount of methyl bromide (see above). Immediately upon introducing the methyl bromide, make a careful search for leakage with the halide detector; or, if the vault is equipped with a pressure gauge, watch this closely for signs of leakage. Locate leaks, if present, and stop with caulking compound.

(*6*) Start the timer and circulate the methyl bromide for 30 minutes.

(*7*) Set the damper to EXHAUST, and ventilate for 10 minutes. During the last 5 minutes of this period, open the door to allow better ventilation. Do not enter the vault until the end of this ventilating period.

(*8*) Remove bags from the vault and transport to the dressing station or entrance to the "shake-out" room, identify, and return to owners.

(*9*) The men shake out each garment thoroughly and dress in a well ventilated area. Make occasional tests with the halide detector to assure less than 30 parts per million methyl bromide in the dressing area.

2. Bag fumigation. This method is used only out-of-doors or under shelters with no side walls. Since it is not convenient to vary the amount of methyl bromide used, it is necessary to vary the time for exposure according to temperature, as indicated in the following table:

Temperature degrees Fahrenheit	Length of exposure to 1 ampule methyl bromide
60 or over	½ hour.
50 to 59	1¼ hours.
40 to 49	1¾ hours.
−9 to 39	2¼ hours.

(a) *Equipment and supplies.* Bag fumigation is done in the bags, delousing, QM stock No. 27-B-208. There is an inner pocket for an ampule of methyl bromide, which is broken after the bag is closed. The walls of the bag are of impervious material, and the ends are folded and tied for closing. The fumigant for use in bags is methyl bromide, 20 cc ampules, QM stock No. 51-M-888.

(b) *Procedure.* A numbered bag and identifying tag is issued to each man who places therein all his clothing and equipment. The operator inserts an ampule of methyl bromide, closes the bag, lays the bag on its side, and releases the gas within the bag by breaking the ampule. During the period of exposure (see above table for time required) the men proceed with personal disinfestation as described in *a* (2) (*b*) above. At the end of the exposure period, the bags are identified, opened, and emptied, care being taken to avoid breathing the gas. After airing for 5 minutes, the clothing may be worn, each garment being first shaken thoroughly.

3. Pit fumigation. When vaults or delousing bags are not available, it may be necessary to use a pit. By digging a hole 5 feet deep and 5 feet in diameter, space is made for about 20 barrack bags. The hole is covered with tar paper, rubberized raincoats, or other impervious covering, the edges of which are sealed by covering with earth. About 1 pound of methyl bromide is required to fumigate each 12 to 20 bags. Care must be used in releasing the methyl bromide, so that none of the liquid will spill on the hands. If chilled with an ice-salt mixture for half an hour, the can may be pierced with an ordinary nail in relative safety. The opened can is immediately dropped on top of the bags, and the pit sealed. After the required time of fumigation (same as in *2* above), the bags are removed on the windward side with a hooked pole or other suitable means. The clothes are shaken out on the ground to air.

(3) *Steam sterilization.* Disinfestation of clothing, bedding, and infested equipment by steam will kill lice, their eggs, and the ricketsia which cause typhus fever. However, due to the injurious effects of steam on woolens and leather, this method has been largely replaced by other procedures. If a hospital should have occasion to admit a typhus fever patient, the clothing may be boiled for several minutes or soaked in cresol solution before laundering by standard quartermaster formulas. If facilities for steam sterilization are available, materials which are not injured by steam may be both disinfested and disinfected by autoclaving at 15 pounds pressure for at least 15 minutes. Since steam sterilization or boiling is applicable to certain types of material only, supplemental methods of disinfestation will be required.

(4) *Storage.* Storage of infested clothing and equipment will accomplish disinfestation by depriving the lice of a food supply. The exact time required is dependent on the temperature. A safe rule is to keep articles in storage at least 30 days. If the temperature is continuously (day and night) above 70° F., 21 days is sufficient. In this time the eggs will have hatched, and the newly hatched nymphs and the adults will have died. This method is practical for disinfesting clothing and blankets in hospitals and camps, providing storage facilities are available. Rodents and all other forms of animal life upon which lice may feed must be excluded. Fresh material which may be infested should not be placed with that which has been in storage for some time. No articles should be removed from a room until all articles have been in storage the full period of either 21 or 30 days.

(5) *Other methods.* Exposure of infested clothing, bedding, or equipment to a temperature of −10° F. or colder for at least 2 hours will destroy lice and their eggs. The interior of folded or packed materials must be allowed to reach the required temperature before measuring the 2-hour period. Laundering of clothing by the quartermaster laundry formulas, or dry cleaning, will disinfect clothing, but provision should be made to prevent infestation of the laundry or cleaning establishment and its operators and the reinfestation of clothing subsequent to laundering or cleaning. Heat, as in pressing, in the absence of more desirable methods, may be used to destroy lice and eggs in the seams of garments.

3. FLEAS. *a. General.* The presence of fleas at any time will require that procedures for their extermination be instituted. Where human fleas, such as *Pulex irritans*, are present, measures must be directed toward the use of repellents and insecticides by individuals, besides the institution of general control procedures. Thorough housecleaning should be directed toward the removal of breeding material—such as dust and the fecal material of insects and rodents—from floor cracks, corners, from under floor coverings, and from within packing boxes, and toward the dusting of these places with insecticide, powder, louse. Such warm blooded animals as rodents (including bats) and, as far as practical, birds which have access to buildings occupied by troops should be destroyed or excluded, as indicated. All pets and nonmilitary domestic animals should be treated with insecticide or excluded from troop quarters. Insecticide, powder, louse, in a strength of 5 percent DDT (half strength), should be applied to infested military animals, repeating the treatment at such intervals as existing conditions may necessitate. Kennels and animal quarters may be dusted with half-strength insecticide, powder, louse or sprayed with residual spray, caution being taken to not allow animals to come in contact with sprayed areas until after they have been well ventilated and well dried. When packing organizational equipment for movement, all shipping containers should be cleaned, insecticide, spray, residual effect or insecticide, powder, louse, should be applied to the interior of boxes, and textiles should be dusted with louse powder.

b. Conveyances. The interior of trucks, planes, boats, or other conveyances should be inspected prior to loading for movement and,

(1910)

ties under such conditions can be observed and recorded. The real obstacles are two: The length of time required when dealing with long-lived plants and, in any case, the effort required to hold destruction from any cause at a minimum.

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MB Insects Clothes

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UNITED STATES DEPARTMENT OF AGRICULTURE

Methyl Bromide as a Delousing Agent[1, 2]

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CONTENTS

SUMMARY

In January 1942 the Office of the Surgeon General, United States Army, requested the Bureau of Entomology and Plant Quarantine to conduct tests with available fumigants to determine their value as agents for delousing clothing and equipment. After preliminary tests with several fumigants had been made, representatives of the Surgeon General's Office selected methyl bromide as the one best

[1] ... Dove, and W. G. Bruce assisted in the preliminary tests. A. W. Morrill, Jr., ... in certain tests and in the care of insect supplies. A. H. Yeomans designed the demountable fumigation vault and assisted in designing the individual fumigation bag, both of which are described in a previous publication. (LATTA, R., and YEOMANS, A. H. METHODS AND EQUIPMENT FOR FUMIGATION OF CLOTHING INFESTED WITH ... Jour. Econ. Ent. 36: 402-404, illus. 1943.)

[2] Acknowledgments are due to Col. W. B. Stone, Lt. Col. H. C. Cushing, Lt. Col. A. L. ..., and Capt. F. S. Blanton, of the Office of the Surgeon General, and John F. ..., architect, Office of the Chief of Engineers, U. S. Army, for suggestions and ..., and also to other members of the Office of the Surgeon General, the Office of the Quartermaster General, and the Bureau of Entomology and Plant Quarantine, ... United States Army.

12

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suited for their purpose. Further studies were then made to adapt the method of applying this fumigant to their requirements. The egg stage of the body louse (*Pediculus humanus corporis* Deg.) was used in biological tests, because it was indicated as being the most resistant stage of the insect.

Three methods of application were developed, as follows: (1) Vault fumigation, in which quantities of bagged clothing were exposed to methyl bromide in a demountable gastight vault, (2) individual-bag fumigation, in which one soldier's outfit was exposed in a gastight fumigation bag, and (3) pit fumigation, in which from one to many bags of clothing were fumigated in a pit dug in the ground.

A demountable vault, consisting of plywood panels which could be rapidly bolted together to form a fumigation chamber, was designed and built. Tests made in this unit resulted in recommendations of a dosage of 9 pounds of methyl bromide per 1,000 cubic feet of space (three 1-pound cans per 330-cubic-foot vault) at temperatures above 60° F., or 12 pounds per 1,000 cubic feet (four 1-pound cans per vault) at temperatures below 60°. Damp clothing was successfully fumigated, but the method was not successful with clothing wet enough so that water could be wrung from it by hand.

An individual fumigation bag from 25 to 28 inches wide and ... inches long, made of material coated with either ethyl cellulose or Neoprene to make it relatively gastight, and fitted with a simple, self-contained closure, was developed. The methyl bromide was contained in a glass ampoule, which was broken inside the sealed fumigation bag. A standard dosage of 20 cc. per bag was selected after dosage-exposure combinations had been compared. All variations in dosage schedules for various temperature levels were then obtained by changing the length of exposure by ...-hour steps from three-fourths hour at 55° F. or above, to 2½ hours at 34° and below. The same exposure to cold alone at −10° ... below was equally effective. In the experimental studies the effect of other closures, various coating materials and fabrics, the position of the bag, and the location of the ampoule were tested.

Pit fumigation at dosages comparable to those used in the other methods, was also found to be effective. The best results were obtained with a pit having a small opening and covers made of gastight materials.

It was demonstrated that methyl bromide could be rapidly removed from clothing by aeration. Even without aeration no dermatitis resulted in tests with Army personnel.

Methyl bromide fumigation has been utilized by the armed forces in both the field and at permanent delousing stations at ports of debarkation. Hundreds of thousands of prisoners of war and returning Army personnel have been processed through such stations.

INTRODUCTION

At the time of the entrance of the United States into World War II louse-borne typhus was a problem of great concern to the

...States Army. Methods of delousing clothing, mainly by ... sterilization, which had been developed during World War I, ... considered outmoded, or they required equipment which was heavy and expensive. Accordingly, in January 1942 the Office of the Surgeon General of the Army requested the Bureau of Entomology and Plant Quarantine to conduct tests with available fumigants to ascertain whether they could be used under military conditions. A fumigant rapid in action, noninjurious to clothing and equipment, effective at low temperatures, not too dangerous to handle, and with no undesirable postfumigation residues or unpleasant odors was desired.

Preliminary studies were made with several fumigants, from which representatives of the Surgeon General's office selected methyl bromide as the one best suited for their purpose. Further studies were then made to develop proper dosage schedules and equipment for adapting this fumigant to the problem. The tests were performed at the Agricultural Research Center, Beltsville, Md.

The trend of the experimental work was determined largely by the concurrent adaptation of the method by the Office of the Surgeon General. The progress was periodically reviewed as each stage of the work was completed, and new problems were attacked in the order of their importance from the standpoint of adaptation of the method.

BIOLOGICAL TECHNIQUE

Early tests showed that the egg of the body louse (*Pediculus humanus corporis* Deg.) was the stage most resistant to fumigants. Therefore, practically all tests were made with eggs. The evaluation of each test was based on whether or not the eggs hatched. At first the eggs, representing all possible ages, were collected from clothing of infested humans. Later, eggs of known age from a colony reared at the Orlando, Fla., laboratory of the Bureau were used. These eggs were shipped by air mail to Beltsville at frequent intervals.

In all tests small pieces of cloth to which the eggs were attached ... were inserted at selected locations in the fumigation enclosure. These pieces were aired following treatment and then kept in a moist, warm environment until the eggs hatched. At first samples were incubated in individual shell vials, which were plugged with cotton and kept at a constant temperature of 80° F. and a relative humidity of approximately 50 to 60 percent. Under these conditions hatching was irregular, sometimes extending over a period of 15 days or more. When the temperature was raised to 90° and the relative humidity to near saturation, the eggs hatched in ... 10 days and the percentage of hatch was much higher.

A control sample representing each source lot of eggs in each test was incubated along with the treated eggs, as a check on their viability. The results of hatching in the check samples were recorded, but in only one case are they given in the tables of data, since only tests in which eggs hatched, or in which checks indicated the sample to have adequate viability, are presented. The

13

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data on the hatching of controls, given in table 8, are representative of all control samples. Since the records of hatching are expressed in relation to the occurrence or absence of hatching, comparisons between treatments should be made on that basis. Proportionate amounts of hatching are unreliable, because the check samples varied considerably in this respect. In some samples the total number of eggs was estimated, but in most samples the eggs were actually counted.

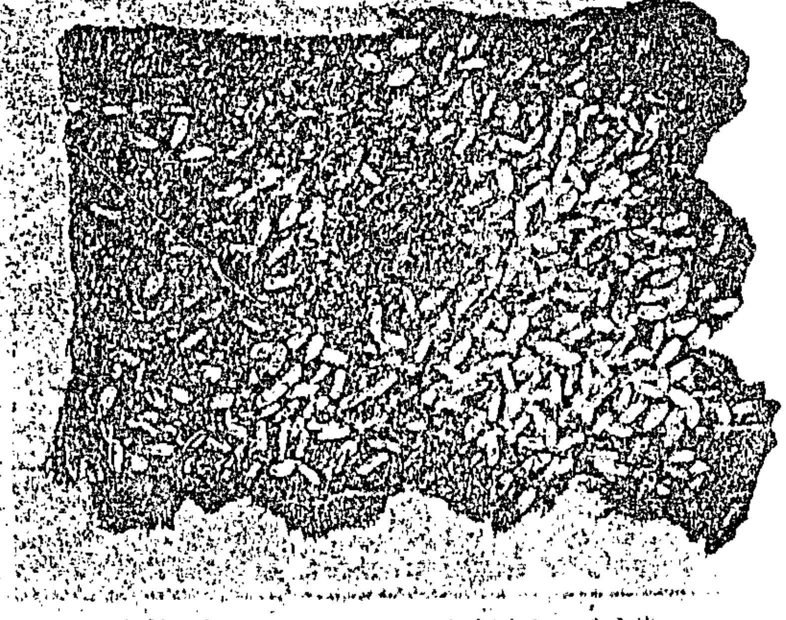

FIGURE 1.—Louse eggs attached to piece of cloth.

PRELIMINARY EXPERIMENTS WITH VARIOUS FUMIGANTS

Seven fumigants were tested in preliminary experiment[illegible] follows: Acrylonitrile, calcium cyanide (dust), chlor[illegible] 1,1-dichloro-1-nitroethane (Ethide), ethylene dichloride, [illegible] bromide, and a mixture of 75 percent of ethylene oxide and 25 [illegible] of ethylene dichloride (Oxyfume).

The tests were made by three methods, as follows: (1) [illegible] water-sealed drum-type fumigator with a capacity of 7[illegible] feet, (2) in a gastight bag with a capacity of approximate[illegible] cubic feet, and (3) in a metal-lined chamber with a capacit[illegible] 107 cubic feet. Not all fumigants were tested under all t[illegible] methods. All eggs used in these tests were taken from natu[illegible]

DRUM-FUMIGATOR METHOD

[illegible]hloropicrin, calcium cyanide, and methyl bromide were tested by [illegible]method, both with and without a load of clothing in the drum, [illegible]ith 30-minute exposure of louse eggs. Tests were made in a [illegible]allon drum converted into a water-sealed chamber, as described [illegible]ohnson,[4] fitted with a small electric fan to circulate the fumi[illegible] properly. The results are given in table 1.

[illegible] 1.—*Hatching of louse eggs after 30-minute exposure to chloropicrin, [illegible] cyanide, and methyl bromide in a drum fumigator (1 test at each [illegible] unless otherwise indicated)*

NO CLOTHING PRESENT

Fumigant	Temperature (to nearest 5°)	Dosage per 1,000 cubic feet	Eggs exposed: Total	Eggs exposed: Hatched
	° F.	Pounds	Number	Number
	40	14.6	21	1
	50	2.4	27	8
	50	4.8	41	9
	60	2.4	66	21
	60	[1] 4.8	230	36
	60	7.3	140	5
	60	9.7	100	0
	60	[1] 14.6	200	0
[illegible]picrin	60	20.3	100	0
	70	3.6	100	0
	70	9.7	100	0
	70	[1] 14.6	200	0
	80	4.8	14	0
	80	9.7	31	0
	80	[1] 14.6	140	0
	90	4.8	100	0
	90	9.7	100	0
	90	14.6	100	0
[illegible] cyanide	70	4.1	100	0
	60	4	60	0
[illegible] bromide	60	6	55	0
	60	8	182	0

CLOTHING PRESENT (load 2 lb. per cubic foot unless otherwise indicated)

Fumigant	Temperature (to nearest 5°)	Dosage per 1,000 cubic feet	Eggs exposed: Total	Eggs exposed: Hatched
	50	21.9	200	21
	55	14.6	200	28
[illegible]	60	4.8	200	149
	60	7.3	200	98
	60	9.7	200	200
	60	14.6	200	11
[illegible] cyanide	70	[1] 1	100	90
	60	[1] 4	200	[illegible]
	60	[1] 5	200	67
	65	[1] 3	200	6
	65	[1] 4	200	4
	65	[1] 1	200	0
[illegible] bromide	65	[1] 5	200	1
	65	[1] 6	200	0
	70	2	200	60
	70	3	200	29
	70	4	100	1
	70	6	100	0

[1] Exposure period 1 hour.
[2] Load 4 lb. per cubic foot.

[illegible] where eggs were exposed directly to the fumigants with[illegible] clothing present, all three fumigants appeared to be effective. [illegible] load of clothing was introduced, however, chloropicrin and

[4] [illegible] C. A LOW-COST WATER SEAL FUMIGATOR. U. S. Bur. Ent. and Plant

14

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calcium cyanide were relatively ineffective, and methyl bromide was effective only with dosages of 4 pounds or more per 1,000 cubic feet.

GASTIGHT-BAG METHOD

About 25 pounds of Army clothing were loosely packed in a gastight bag (described on pages 15–16). Two samples of louse eggs

TABLE 2.—*Hatching of louse eggs after exposure to various fumigants in a gastight bag filled with clothing (100 eggs exposed, unless otherwise indicated*

Fumigant	Exposure	Dosage per bag	Temperature	[illegible]
	Hours	*Cubic centimeters*	*° F.*	*Num-*
Acrylonitrile	2½	5	80	
	2½	15	80	
	2½	30	80	
	2½	60	80	
	6	15	65	
	10	10	84-69	
	17½	15	87-64	
		Ounces		
Calcium cyanide	2	1	85	
	2	2	85	
	6	5	65	
	16½	1	78-85	
	15½	2	77-86	
	16	2	83-69	
		Cubic centimeters		
Chloropicrin	6	2½	65	
	6	5	65	
	6	10	65	
	6	10	65	
	6	25	65	
	6	50	65	
	6	100	65	
1, 1-Dichloro-1-nitroethane	6	10	62	
	6	25	62	
	6	100	62	
Ethylene dichloride	2	8	80	
	2	32	84	
	2	100	84	
	6	200	65	
	7½	60	60	
	16	24	85-78	
	15½	48	80-77	
	14	100	60-53	
	15	100	....	
Ethylene oxide-ethylene dichloride, 75-25 mixture	6	2	66	
	6	4	60	
	6	8	66	
	6	16	60	
	6	25	60	
	6	50	65	
	6	100	65	
	6	200	65	
Methyl bromide	½	5	62	
	½	10	62	
	½	15	67	
	½	16	67	
	½	21	67	
	½	25	67	
	1	16	67	
	1	21	67	
	1	25	67	
	6	1	65	
	6	2	65	
	6	4	65	
	6	5	65	

[1] 150 eggs exposed.

were placed in each bag, one in the center of a folded blanket at the bottom, and one rolled in woolen underwear at the center. The fumigant was poured or otherwise liberated at the top of the bag. The tests were directed mostly toward medium to long exposure periods (table 2). The temperatures given for overnight exposures are those taken at the beginning and end of each period. Chloropicrin and methyl bromide produced the best results, with acrylonitrile, 1,1-dichloro-1-nitroethane, ethylene oxide-ethylene dichloride mixture following in that order. Calcium cyanide and ethylene dichloride gave poor results.

USE OF A METAL-LINED CHAMBER

In another series of tests chloropicrin and methyl bromide were compared in a metal-lined vault of a type commonly used for other fumigation purposes. Except for one exposure of 1 hour, the periods were limited to 30 minutes. The vault had a capacity of 107 cubic feet. All openings were carefully fitted with sponge-rubber gaskets to make the vault gastight. Circulation was provided by a small fan.

In each test clothing at the rate of 2 to 3 pounds per cubic foot was present in the chamber. The louse-egg samples, numbering from 3 to 10, were scattered throughout the load, some of them being placed in the folds of clothing at the centers of well-filled barracks bags. Circulation was maintained throughout the exposure period.

Methyl bromide at the rate of 6 pounds per 1,000 cubic feet produced complete mortality, but chloropicrin was not effective in any test, even when the exposure period was increased to 1 hour (table 3).

TABLE 3.—*Hatching of louse eggs after half-hour exposure to two fumigants in a metal-lined chamber*

Fumigant	Dosage per 1,000 cubic feet	Temperature	Load per cubic foot	Eggs exposed	
				Total	Hatched
	Pounds	*° F.*	*Pounds*	*Number*	*Number*
Chloropicrin	4.8	65	2	400	112
	10.9	70	2	400	137
	14.6	59	2	600	391
	14.6	55	3	1,000	435
	14.6	57	2	600	187
	14.6	70	2	300	[illegible]
	[1] 14.6	65	2½	400	133
Methyl bromide	4	45	3	800	73
	4	65	4	300	19
	4	70	2	400	1
	5	46	3	800	44
	5	62	3	300	3
	6	50	3	800	[illegible]
	6	60	2	100	0
	6	76	2	400	0

[1] Exposure period 1 hour.

15

Discussion

On the basis of these tests methyl bromide was selected as the best fumigant to use in further experimentation. It was the most effective fumigant tried, did not stain clothing, left no odor, was noninflammable, and apparently did not react with articles, especially those made of plastics, that might be included in a soldier's equipment. It was the only fumigant of the series with a low boiling point, apparently an important feature in the consideration of short exposure periods.

Chloropicrin was highly efficient in 6-hour exposures, but was ineffective in short exposures, even with excessive dosages. Also, enough was retained in the clothing to produce tears in the eyes of the wearer several hours afterwards.

Acrylonitrile was inflammable, and much greater quantities of it were required than of methyl bromide or chloropicrin. In individual fumigation-bag tests 1,1-dichloro-1-nitroethane was effective at approximately the same dosage as acrylonitrile, but it left a lingering odor in clothing. The mixture of ethylene oxide and ethylene dichloride was also inflammable, and even greater dosages of it were required than of the above-named fumigants. Calcium cyanide was ineffective, left an odor in clothing, and often stained garments that were moist or sweaty. Ethylene dichloride was not efficient, even in 6-hour exposures, and was also inflammable.

FURTHER EXPERIMENTS WITH METHYL BROMIDE

After the preliminary tests had been completed, studies were concentrated on the use of methyl bromide. Three methods of application were developed, and exhaustive studies were conducted on each of these to determine dosage schedules suitable under various conditions. These methods were (1) vault fumigation, in which quantities of clothing were exposed to methyl bromide in a demountable gastight vault; (2) individual-bag fumigation, in which one soldier's outfit was exposed in a gastight fumigation bag, the fumigant being applied by breaking a glass ampoule containing the exact dosage; and (3) pit fumigation, in which from one to many bags of clothing were fumigated in a pit dug in the ground, the opening being sealed by paper, raincoats, tarpaulins, or other means.

The equipment and biological data for each of these methods will be discussed fully under their respective headings.

Vault Fumigation

The military authorities desired a lightweight, demountable fumigation vault of noncritical materials, of a size convenient for transportation when demounted and best suited for efficient operation. An experimental model 9 by 6 by 4½ feet was designed and constructed for demonstration to military personnel. This model was tentatively approved and experimental studies were conducted in it to establish suitable dosage schedules.

The vault was made of sections bolted together to make the complete chamber (fig. 2). All joints were sealed with a nonhardening

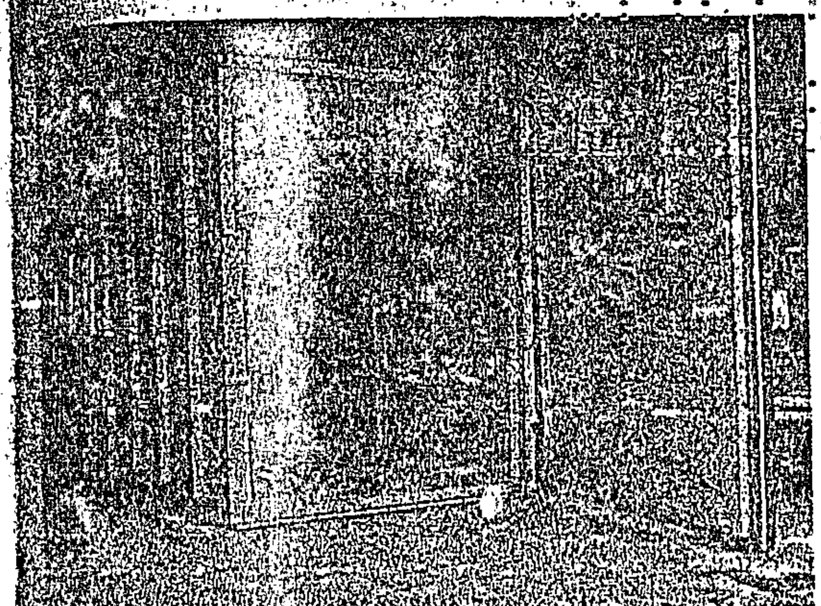

Figure 2.—Experimental demountable fumigation vault.

Figure 3.—Front view of experimental fumigation vault, showing complete end

16

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bituminous calking compound to make them gastight. Each sect[ion] consisted of a single sheet of five-ply, half-inch plywood, reinfor[ced] around the edges by a 2- by 2-inch strip. The top, bottom, a[nd] side sections consisted of two panels each. The front-end sect[ion] served as a door (fig. 3) and closed against rubber-strip gask[ets]. It was fitted with double pin hinges, and a series of clamps arou[nd] the complete perimeter served to fasten it tightly and evenly aga[inst] the gaskets. A small intake vent was located in this door pa[nel]

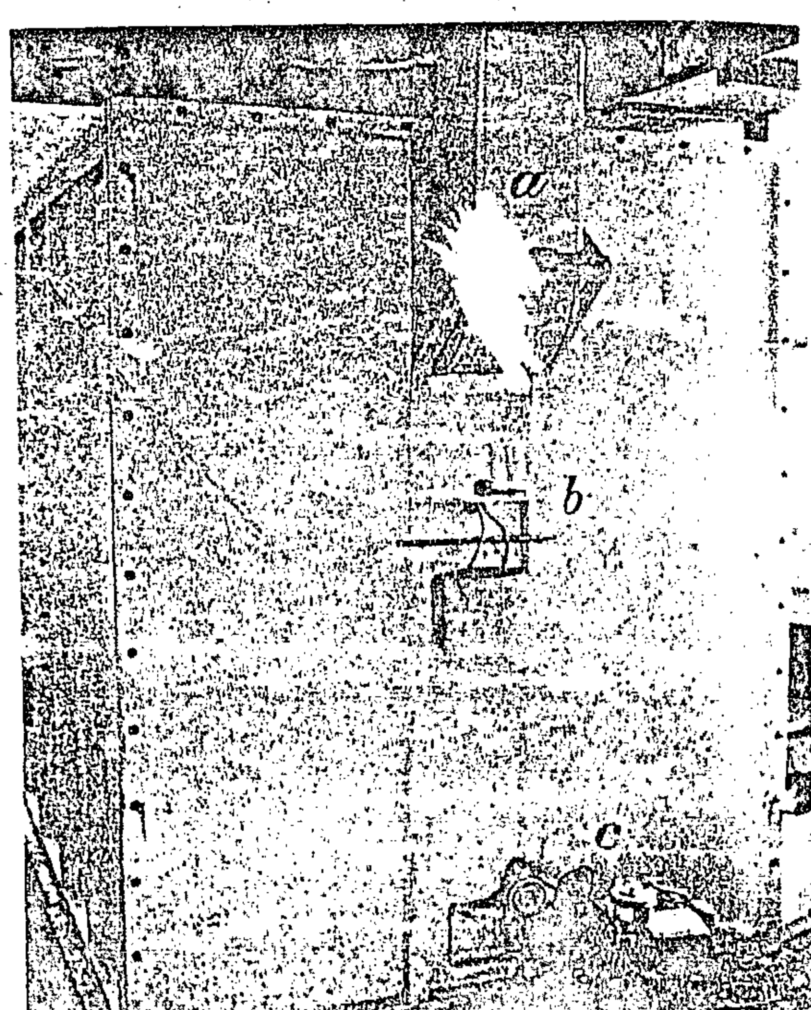
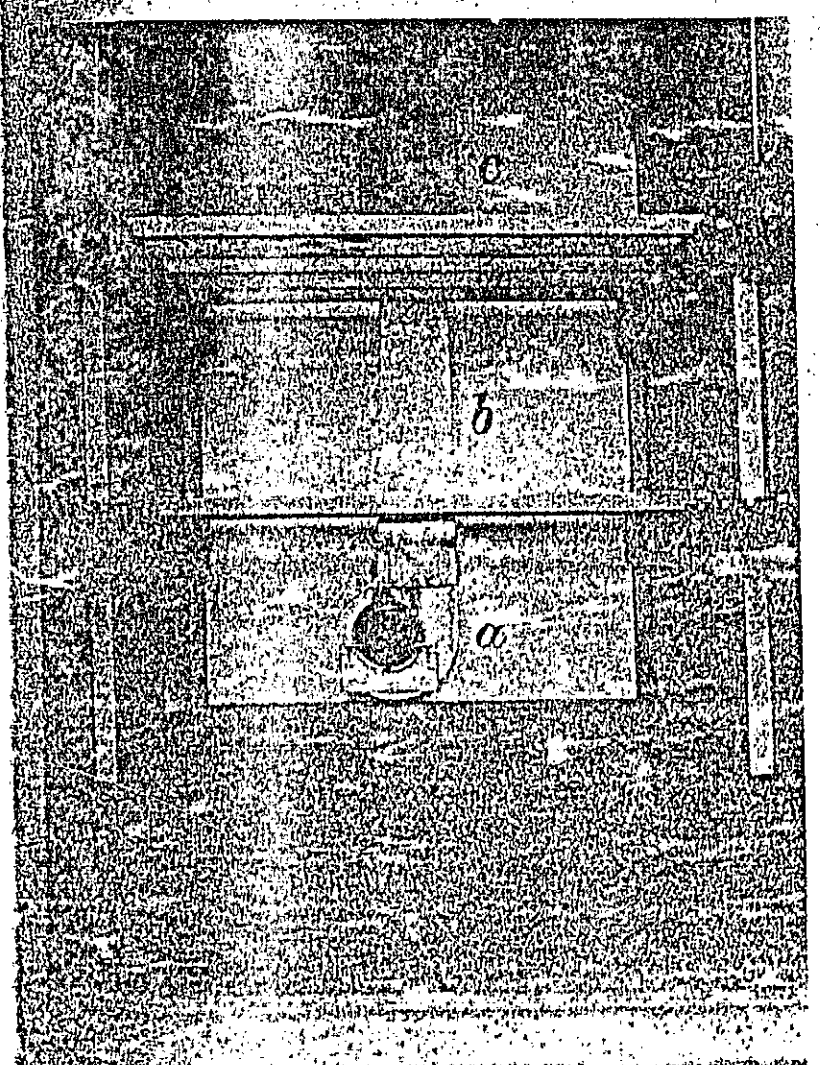


FIGURE 4.—Rear view of experimental fumigation vault, showing (a) [illegible] vent, (b) methyl bromide applicator and volatilizer, and (c) gasoline [illegible]

[illegible] opened when it was desired to allow fresh air to pass into [the] vault. The vent door also closed against rubber gaskets. The [rear-]end section carried all the operational equipment (fig. 4). A [gasoline] blower provided circulation during the fumigation and [exhaust]ing of the fumigant following treatment. It was mounted at [floor] level (fig. 5) with the outlet directed upward into a short duct on [illegible]



[FIGURE 5.]—Interior view of experimental fumigation vault, showing location [of] (a) blower, (b) circulation duct, and (c) exhaust-vent door. The method [of] shelving is also shown.

17

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the center of the panel. Directly above this duct was located the exhaust-vent opening. The vent door, when closed, was flat against the rear panel and allowed the air stream to pass without interruption. When opened, the lower edge of the vent door protruded completely across the opening of the circulation duct, and served as a baffle to direct the discharge of the blower through the vent into the exhaust duct. Simultaneous opening of the intake vent in the front panel allowed a rapid removal of the fumigant. When closed, the exhaust-vent door was seated against rubber gaskets. It was actuated by a threaded rod, attached to its center and projected through a small opening in the exhaust duct. To close the vent, a wing nut on the threaded rod was tightened. A strap-iron frame around the outside of the exhaust duct received the stress of this operation (fig. 6). Exterior and interior views of the exhaust system are shown in figures 4 and 5.

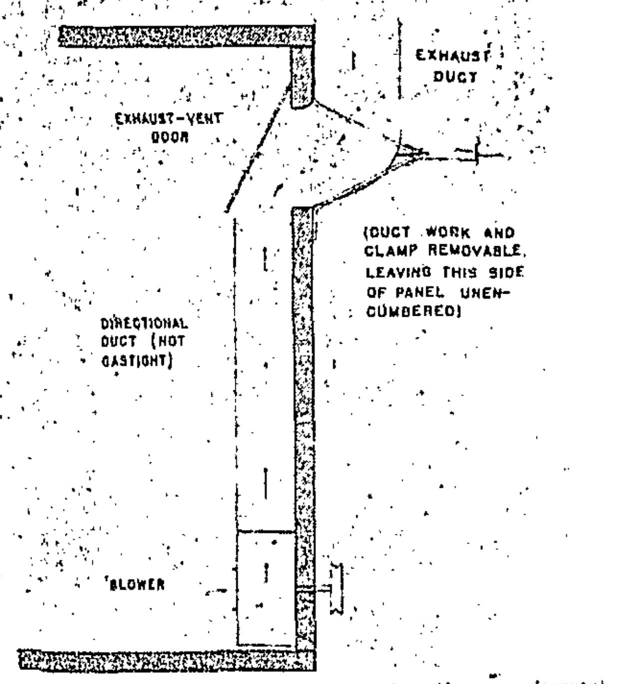

FIGURE 6.—Diagram of the exhaust system used on the experimental fumigation vault.

The blower was driven by a gasoline motor (fig. 4, *C*) placed outside the rear panel and operated throughout the exposure period to hasten penetration. The capacity of the blower was large enough to provide for rapid venting, and a 10-minute period was adequate for the removal of all free methyl bromide in the vault. The blower was operated during unloading, which kept a drift of fresh [illegible] any

additional fumes that were dissipating from the gas absorbed in the clothing. Under these conditions it was not deemed necessary for an operator to use a gas mask, because he would seldom be exposed to appreciable concentrations of methyl bromide for any length of time.[6]

The methyl bromide was applied from 1-pound cans. The cans were punctured by tightening an ingenious clamp arrangement. Before entering the chamber, the fumigant passed through a volatilizer consisting of a coil of copper tubing suspended in a can of hot water.

Removable racks inside the vault were made by placing 2- by 2-inch bars of proper length in notched strips on the side panels (fig. 6).

No arrangement was made for heating the vault or its contents, because it was known that methyl bromide fumigation could be made effective at lower temperatures by increasing either the dosage or the exposure period.

The dismantled vault including the motor weighed 809 pounds. Later models built by the Quartermaster Corps were increased in size to 330 cubic feet, and the top, bottom, and side sections consisted of only one panel each.

The preliminary tests with methyl bromide had indicated that at a temperature of 60° F. or above, and with 30-minute exposures, a dosage of 6 pounds per 1,000 cubic feet was almost completely effective (table 3). Twenty-one tests were made in the experimental vault with loads of clothing present in each. A dosage of 8 pounds per 1,000 cubic feet was decided upon for these tests, as this rate (two 1-pound cans of methyl bromide in 250 cubic feet) had predetermined the capacity of the vault. One test was made with half this dosage, and in one where wet clothing was involved the dosage was increased to 12 pounds.

Loads of 3 and 5 pounds per cubic foot of space (30 and 50 barracks bags per load) were used. All loads were made up of barracks bags each containing one winter outfit (wool uniform, overcoat, underwear, shirt, shoes, socks, and two blankets) weighing approximately 25 pounds. The preliminary tests had shown that the fumigant would penetrate to the center of loaded barracks bags without undue delay.

In relation to wetness, four types of clothing were used, as follows: (1) Dry clothing, in normal condition. (2) Damp to wet clothing, containing water equal to about 35 to 40 percent of its weight. This was the limit of water that could be contained in the garments without the operator being able to wring out by hand any appreciable amount. This condition was produced by soaking the clothing and allowing it to drain for 2 days, by sprinkling it, or by exposing it to natural rainfall (1½ inches in one instance). (3) Wet clothing, containing water equal to about 50 percent of its weight. This condition was obtained by soaking the clothing and allowing it to drain overnight. (4) Very wet clothing, containing

[6] Methyl bromide, like all fumigants, is injurious to all *forms of animal life* when inhaled in sufficient quantities. One should observe proper precautions when handling it to prevent exposure to the fumes. An operator should use an approved gas mask when exposed to the gas at fumigation concentrations. All piping or tubing carrying methyl bromide should be checked frequently to prevent leakage.

water equal to about 65 percent of its weight. This condition [illegible] obtained by soaking the clothing and briefly draining it.

The bags of clothing were so placed on the removable rack[illegible] the fumigation vault as to leave a space between the layers (fig. 7)

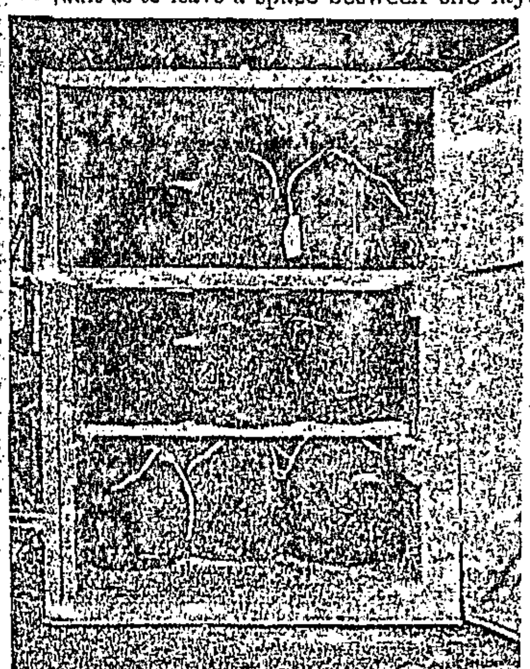

FIGURE 7.—Experimental fumigation vault with barracks bags loaded in three tiers.

Trials were made with the bags divided into two and three [illegible] but no differences in results were noted. The temperature of [illegible] clothing was noted at the start of each test, and a thermogr[illegible] record was made of the vault temperature during each exposu[illegible]

Samples of viable louse eggs in small cloth bags were placed [illegible] folded garments or blankets in the center of selected barracks [illegible] scattered throughout the load, an equal number being on each [illegible] The samples of louse eggs in damp or wet clothing were [illegible] about the same condition as the clothing with which they were [illegible]cluded. In all except two tests the eggs were from infested clo[illegible] obtained in the District of Columbia. Two lots of eggs were [illegible] the Orlando, Fla., laboratory. The eggs from infested clothing [illegible] of all ages, as shown by the hatching of the check samples. [illegible] were segregated so that control and treated samples from [illegible] garment or one person could be identified. The hatching la[illegible] were counted and removed daily from each sample. The number [illegible] eggs in each sample was estimated, but the number of larvae hatc[illegible] was an actual count.

The results are given in table 4. With dry clothing no hatchi[illegible] occurred in 9 tests where the temperature was 60° F. or above. [illegible]

[illegible]enth test, at 55° F., 1 larva hatched from an estimated 275 [illegible] When half-dosage (4 lb. per 1,000 cu. ft.) was used, only [illegible] 4 percent of the eggs hatched.

[illegible]—*Hatching of louse eggs after half-hour exposure to methyl bromide [illegible] F. or above, in a demountable plywood vault loaded with 30 to 50 bags [illegible] clothing*

Condition of clothing	Dosage per 1,000 cubic feet	Total samples	Total eggs exposed	Eggs hatched	Fumigation tests: Total	Fumigation tests: Completely effective
	Pounds	*Number*	*Number*	*Number*	*Number*	*Number*
[illegible]	4	6	500	21	1	0
[illegible]	8	58	5,820	1	10	9
[illegible] wet (35 percent added water)	8	20	878	0	4	4
[illegible] percent added water)	8	19	635	65	3	0
[illegible] (65 percent added water)	8	13	1,010	307	2	0
	12	6	230	15	1	0

In damp to wet clothing complete mortality of louse eggs was [illegible] in all tests. In wet clothing the results were variable, with [illegible] in at least one sample in each test. In very wet clothing [illegible] treatment was definitely not effective, even in the last test, [illegible] the dosage was increased 50 percent (12 lb. per 1,000 cu. ft.).

It was evident from these tests that dry or damp clothing could be fumigated successfully, but that clothing wet enough so that water could be wrung from it by hand should not be fumigated.

On the basis of these experiments a dosage schedule, for vault fumigation, of 8 pounds per 1,000 cubic feet for one-half hour [illegible] 60° F. or above, with a load limit of 5 pounds of clothing per cubic foot of space, was recommended to the Surgeon General's Office. A fumigation vault similar to the experimental model was [illegible] recommended. In drawing up specifications for procurement of [illegible] vaults, United States Army authorities raised the capacity to [illegible] cubic feet, for better efficiency in operation. Since it was desired to keep the total dosage per vault in an even number of pounds, the [illegible] was raised to 9 pounds per 1,000 cubic feet.

Later, when the data obtained in the tests represented in figure 12 [illegible] nearly completed, recommendations were made for dosage schedules at lower temperatures, proportional to the rate of 9 pounds per 1,000 cubic feet at 60° F. or above, as follows: At 60° and [illegible], use 3 pounds per vault or 9 pounds per 1,000 cubic feet, for one-half hour. Below 60° either use 4 pounds per vault or 12 pounds per [illegible] cubic feet, or add one-half hour of exposure for each 10° below [illegible] The mass temperature of the clothing, not that of the air, should [illegible] the determining point.

INDIVIDUAL-BAG FUMIGATION

The individual fumigation bag used in the preliminary tests with [illegible] fumigants (pages 6–7) was approximately 28 inches wide [illegible] 50 inches long, and made of light-weight duck coated with 19
[illegible] layers of ethyl cellulose (fig. 8). The exact quantity of fumi[illegible] desired was contained in a glass ampoule, which was placed in[illegible] the bag as it was being filled with clothing. After the fumi-

gation bag was closed and sealed, the ampoule was broken, releasing the fumigant. This method had worked so well in preliminary tests, and had so many obvious advantages for certain purposes, that extensive studies were undertaken to develop its potentialities further.

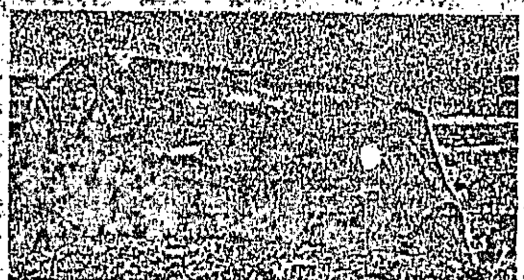

FIGURE 8.—Experimental model of the individual fumigation bag, made of duck coated with ethyl cellulose, and closed by the board-clamp method.

The method of fumigation was standard throughout all the tests. An outfit consisting of clothing and blankets, weighing about 25 pounds, was loosely placed in each fumigation bag. Usually two samples of louse eggs were placed in each bag between the folds of a blanket or garment. The bag was then sealed and the ampoule broken. At the end of the desired exposure period the bag was opened, the clothing was shaken out, and the samples of louse eggs were immediately removed.

Prior to fumigation the clothing and blankets were conditioned at the desired temperature and were held at that temperature during the exposure period. Low-temperature studies were made in cold-storage rooms.

The early tests were made with louse eggs obtained from infested clothing, but the later ones with eggs from the Orlando colony. In low-temperature experiments the eggs were given only a brief exposure to the low temperature prior to fumigation, on the assumption that in actual practice the eggs would be at body temperature until clothing was removed for delousing.

The studies were divided into two general groups as follows: (1) Development of the method, including studies on dosage-exposure combinations, type of closure, position of the bag during fumigation, location of the ampoule in the bag, dimensions of the bag, and materials; and (2) development of dosage schedules, including ones for various temperature levels, and the effects of exposure to cold alone.

DEVELOPMENT OF THE METHOD

DOSAGE-EXPOSURE COMBINATIONS

The preliminary tests with methyl bromide had shown effective dosages as low as 1 cc. per bag for a 6-hour exposure, and effective exposures as short as one-half hour with dosages of 16 cc. and above. Further tests were made, therefore, to determine the minimum dosages required for the two exposure periods.

Minimum Dosages at 6-Hour Exposures

A total of 42 tests were made at 3 temperature levels—65°-70°, 36°, and 25° F. The results are given in detail in table 5. At 70° a dosage of 0.75 cc. per bag appeared to be about the minimum, as 3 of 5 tests at this dosage were completely affective and a fourth had only 1 survivor. In 1 test 1 cc. was completely effective, but 0.5 and 0.25 cc. were definitely ineffective. At 36° a dosage of 2 or 3 cc. per bag appeared to be the minimum. In 5 tests with 2 cc. 3 resulted in complete mortality and only 1 louse survived in a fourth. In 6 tests with 3 cc. the results were similar. In 4 tests 4 cc. was completely effective. At 25° a dosage of 4 cc. per bag was effective in 4 out of 5 tests. This was considered to be the minimum dosage, since 2 and 3 cc. gave irregular results, and 5 and 6 cc. were completely effective.

TABLE 5.—*Hatching of louse eggs after 6-hour exposure to methyl bromide in individual fumigation bags*

Temperature	Dosage per bag	Total samples	Total eggs exposed	Eggs hatched	Fumigation tests: Total	Fumigation tests: Completely effective
°F.	*Cubic centimeters*	*Number*	*Number*	*Number*	*Number*	*Number*
[illegible]	2	8	670	55	4	2
	3	13	1,080	227	4	1
	4	14	1,039	83	5	4
	5	4	342	0	1	1
	6	4	70	0	2	2
[illegible]	2	10	764	12	5	3
	3	14	1,267	45	6	3
	4	10	713	0	4	[illegible]
[illegible]	0.25	4	125	22	2	0
	.5	8	490	104	4	0
	.75	10	700	17	5	3
	1.0	2	70	0	1	1

Minimum Dosages at Short Exposures

In tests with short exposures dosages of 12, 15, and 20 cc. per bag were used, which were both above and below the lethal dosages indicated in the preliminary studies. The 12-cc. dosage allowed a slight recovery in 3 of 16 tests with half-hour exposures, in which 8,190 eggs were used. Four tests with a dosage of 15 cc. for half-hour exposures, involving 3,112 eggs, resulted in complete mortality. Seventeen tests with 20-cc. dosages for half-hour exposures, involving 5,419 eggs, were also completely effective, as were 6 additional tests with the same dosage for three-fourths-hour exposures, in which 1,179 eggs were used.

TYPE OF CLOSURE

In the preliminary tests with individual fumigation bags, the bag was closed for fumigation by folding the open end and clamping the fold between two strips of wood held together by C-clamps, as illustrated in figure 8. This closure was not acceptable to military authorities, because it was composed of detachable parts; therefore other types were devised and tested.

Slide fasteners (zippers), slide clamps, and snaps were successively tried and were discarded for one reason or another. The final arrangement was very simple. It consisted of reinforcing the lips of the open end of the bag (fig. 9A) with webbed-canvas belting,

FIGURE 9.—A fumigation bag with a fold-over-tie closure: A, In open position showing the reinforced but flexible bag opening; B, the same bag closed.

which was flexible longitudinally but relatively rigid in cross section. To seal the bag, the mouth was closed and the end of the bag was folded over the reinforcing strip three times and tied in place with conveniently placed tapes (fig. 9B). While this closure, known as the fold-over-tie closure, was not so tight as that provided by the board clamp, it was found to be efficient and had obvious advantages from the standpoint of production and utility.

Tests to compare the fold-over-tie type with the board-clamp closure were made at half-hour exposures with dosages of 12, 15, and 20 cc. Four tests with each closure resulted in complete mortality at 12-cc. dosages, as did two tests at 15-cc. and five tests at 20-cc. dosages.

POSITION OF BAG DURING FUMIGATION

The usual procedure was to place samples of louse eggs at two locations within the fumigation bag—at the bottom and at the center. In tests where the ampoule of fumigant was placed at the bottom of the bag, and the bag remained upright during the fumigation, eggs survived in the samples at the center of the bag but not in those at the bottom. This occurred more often in Army type-1 bag (see page 21), which was only 24 inches wide, than in the 28-inch type used in the preliminary experiments. The resulting difference in circumference increased the height of the load of clothing, thus also increasing the height of the sample at the center of the bag. In five tests with a dosage of 20 cc., only one produced complete mortality in the center sample when the Army type-1 bag was left upright during the exposure, as compared with complete mortality in seven tests with the bag lying on its side. It was also noted that dosages as low as 12 cc. were highly effective when the bag was laid on its side.

LOCATION OF THE AMPOULE IN THE BAG

Inasmuch as eggs at the center often survived when the ampoule of fumigant was placed at the bottom of the fumigation bag, the available data were analyzed to determine the influence of the location of the ampoule. In one series of experiments using the Army type-1 bag with a 20-cc. ampoule for half-hour exposures, four of five tests had survivors from samples at the center or top of the bags when the bags remained upright. In seven additional tests with the bag on its side, mortality was complete in samples at the center and at the top.

The effect of placing the ampoule at the center of the bag was then determined. With a 20-cc. ampoule and a three-fourths-hour exposure complete mortality resulted in two tests with the bag upright, but in two of three tests with the ampoule located at the bottom there were survivors.

Following these tests a pocket was placed near the top of each fumigation bag to hold the ampoule (fig. 10). An identifying mark was also placed on the outside of the bag to assist in locating the ampoule (perpendicular white line above the word "Read" in fig. 9).

The removal of the ampoule from its individual cardboard container was found to be unnecessary; in fact, the container helped to retain the broken ampoule and protect the bag from glass cuts.

DIMENSIONS OF THE BAG

As noted previously, when the ampoule was placed at the bottom of the bag mortality was incomplete at the center of the bag or above, in upright bags of narrower dimensions than the original experimental model. It was also shown that if the ampoule was located at the center or above, or if the bag was laid on its side, complete mortality resulted. From these tests it was concluded that complete mortality could be ensured by such means, and that the dimensions of the bag could be determined solely by convenience.

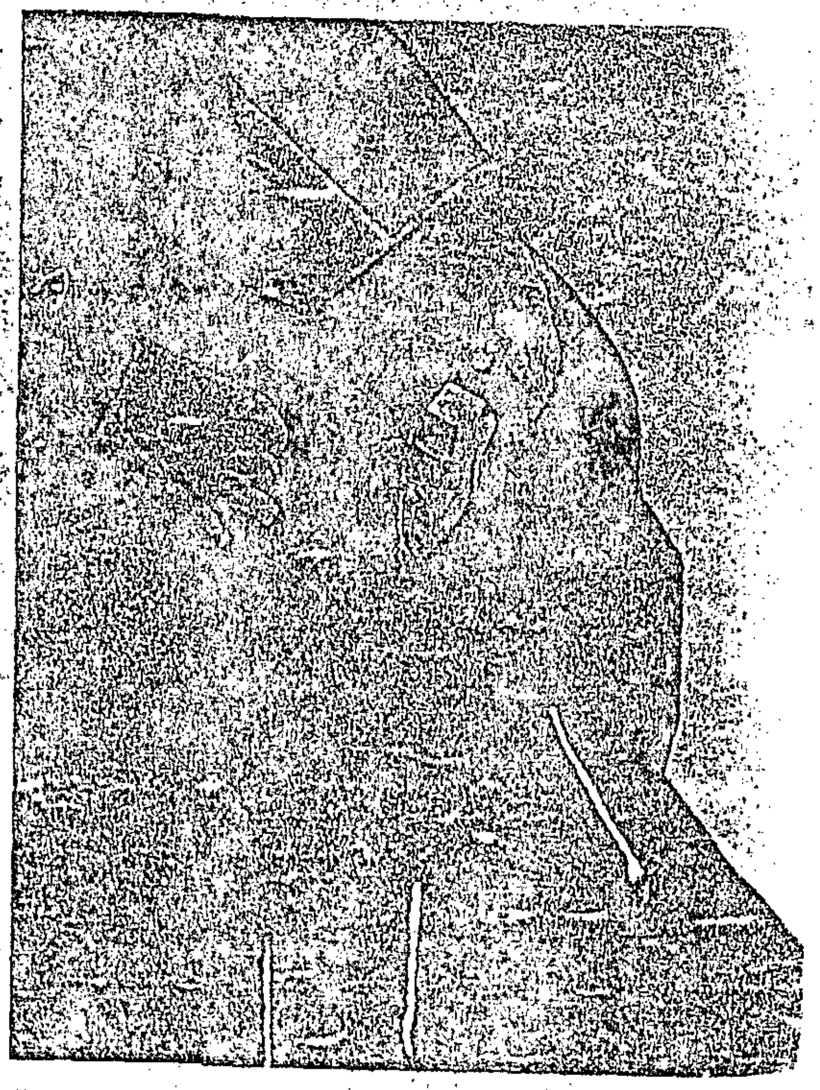

FIGURE 10.—A fumigation bag opened to show the special pocket in which the methyl bromide ampoule is placed.

MATERIALS

In addition to the original fumigation bag of lightweight duck coated with ethyl cellulose, the Army purchased bags similarly made

except that sateen was used instead of the duck. Later a material coated with Neoprene, a synthetic rubber, was used, two layers of sheeting being sealed together and coated on each outer surface with the rubber. Several other coated materials were tested at various times, as well as some paper products. Data on all these are assembled in this section. The materials are described as follows:[6]

(1) A single layer of duck with three coats of ethyl cellulose (laboratory experimental bag).
(2) A single layer of sateen with three coats of ethyl cellulose (Army type-1 bag).
(3) A double layer of sheeting with three layers of Neoprene, one between and one on each outer surface (Army type-2 bag).
(4) Two layers of waterproof paper with an interlining of tar.
(5) Heavy wrapping paper.
(6) A single layer of cloth coated with vinyl resin.
(7) A double layer of cloth coated with vinyl resin.
(8) Neoprene balloon cloth, coated on one side with aluminum, weight 2.05 ounces per square yard.
(9) A double layer of cloth coated with polyvinyl butyl.
(10) A single layer of cloth coated with resin.
(11) A double layer of sheeting coated with Neoprene, similar to (3) above.
(12) A single layer of cloth coated with Vinylite.
(13) Balloon ballinett, a double layer of cloth coated with Neoprene, unaluminized, 8 ounces per square yard.
(14) Balloon ballinett, a double layer of cloth coated with Neoprene, aluminized.
(15) Laminated paper with cloth back.
(16) Paper laminated to cloth.
(17) A double layer of sheeting, with a middle coat between the sheeting of buna S, and outer coatings of Neoprene.
(18) A double layer of sheeting, with three coats of butyl rubber.
(19) A double layer of sheeting with a middle coat between the sheeting of butyl rubber, and outer coatings of Neoprene.

A number of tests were made in which bags of the various materials were compared with bags made of materials 1, 2, and 3. In several instances a sublethal dosage was deliberately used, so that finer comparisons could be made. The results showed that most of the materials were practically as efficient as those coated with ethyl cellulose or Neoprene. A single layer of cloth coated with vinyl resin was probably slightly inferior, and would require an increased dosage. The results of these tests are given in table 6.

DEVELOPMENT OF DOSAGE SCHEDULE

It was already known, when these investigations were begun, that methyl bromide is effective in direct relation to the temperature, and that larger dosages or longer exposures are necessary at the lower temperature levels. Since it was manifestly impractical to have ampoules of various sizes, the variations in dosage schedules were obtained by using different exposure periods.

This method of fumigation was adopted by the Army, and procurement of bags and ampoules was initiated concurrently with the experimental studies. On the basis of preliminary information, a 20-cc. ampoule was selected as the most satisfactory; therefore this dosage was used in all tests. Bags coated with either ethyl cellulose or Neoprene were used in all experiments. The louse eggs were from the Orlando colony, unless otherwise noted.

[6] The descriptions of the materials are incomplete in some instances, but they represent the best information available.

TABLE 6.—*Comparison of bags of various materials with the experimental Army-type bags (dosage, 20 cc. per bag unless otherwise indicated)*

Bag material	Temperature	Exposure	Eggs exposed		Fumigation tests	
			Total	Hatched	Total	Completely effective
	° F.	Hours	Number	Number	Number	Number
(4) Laminated paper	70	6	[1] 215	0	2	
(5) Heavy wrapping paper	70	6	[1] 195	111	2	
(1) Experimental	70	6	[1] 350	0	2	
(6) Vinyl resin, single	0	2¼	1,279	0	2	
(2) Army-type 1	0	2¼	661	2	1	
(3) Army-type 2	0	2¼	502	0	1	
(6) Vinyl resin, single	0	2¼	784	0	2	
(3) Army-type 2	0	2¼	414	0	1	
(6) Vinyl resin, single	25	1¾	1,205	2	2	
(3) Army-type 2	25	1¾	571	4	1	
(6) Vinyl resin, single	32	1½	1,502	14	2	
(3) Army-type 2	32	1½	1,218	0	2	
(6) Vinyl resin, single	40	¾	1,131	0	2	
(3) Army-type 2	40	¾	400	0	1	
(6) Vinyl resin, single	48	½	821	13	2	
(3) Army-type 2	48	½	361	0	1	
(6) Vinyl resin, single	68	½	1,243	143	2	
(3) Army-type 2	68	½	464	0	1	
(6) Vinyl resin, single	68	½	2,014	0	3	
(7) Vinyl resin, double	68	½	768	0	1	
(3) Army-type 2	68	½	743	0	1	
(8) Balloon cloth	70	½	304	12	1	
(9) Polyvinyl butyl	70	½	307	10	1	
(10) Resin-coated	70	½	265	9	1	
(11) Neoprene	70	½	186	0	1	
(3) Army-type 2	70	½	152	0	1	
(12) Vinylite	52	½	360	10	1	
(13) Ballinett	52	½	400	0	1	
(3) Army-type 2	52	½	606	0	2	
(13) Ballinett	40	¾	211	0	1	
(3) Army-type 2	40	¾	285	0	1	
(13) Ballinett	60	¾	401	3	1	
(3) Army-type 2	60	¾	460	66	1	
(13) Ballinett	68	¾	671	1	1	
(3) Army-type 2	68	¾	677	1	1	
(13) Ballinett	65	¾	200	0	1	
(14) Ballinett	65	¾	400	0	2	
(15) Laminated paper	65	¾	200	0	1	
(16) Paper-cloth	65	¾	200	0	1	
(3) Army-type 2	65	¾	200	0	1	
(17) Neoprene-buna S	38	1½	1,110	0	1	
(2) Army-type 1	38	1½	1,078	0	1	
(3) Army-type 2	38	1½	1,055	0	1	
(17) Neoprene-buna S	40	1¼	555	0	1	
(2) Army-type 1	40	1¼	815	0	1	
(3) Army-type 2	40	1¼	673	0	1	
(17) Neoprene-buna S	60	½	685	1	1	
(2) Army-type 1	60	½	665	70	1	
(3) Army-type 2	60	½	800	3	1	
(17) Neoprene-buna S	70	½	715	0	1	
(2) Army-type 1	70	½	310	0	1	
(3) Army-type 2	70	½	500	0	1	

[1] Dosage 0.75 cc. per bag.

TABLE 6.—*Comparison of bags of various materials with the experimental Army-type bags (dosage, 20 cc. per bag unless otherwise indicated)*—Continued

Bag material	Temperature	Exposure	Eggs exposed		Fumigation tests	
			Total	Hatched	Total	Completely effective
	° F.	Hours	Number	Number	Number	Number
[illegible]	50	1	500	1	1	0
[illegible] Army-type 1	50	1	500	2	1	0
[illegible] Army-type 2	50	1	325	3	1	0
[illegible]	55	½	575	0	1	1
[illegible] Neoprene-butyl	55	½	875	2	1	0
[illegible] Army-type 2	55	½	1,400	2	1	0

It was also evident that at some temperatures exposure to cold alone would cause mortality of all stages of lice. The experiments were therefore divided into two groups as follows: (1) To determine adequate exposure periods to use in fumigation at various temperature levels and (2) to determine the effect of exposure to cold alone.

EXPOSURE PERIODS NECESSARY AT VARIOUS TEMPERATURE LEVELS

Louse eggs were fumigated in individual bags with a normal load of 25 pounds of wool clothing and blankets, at temperatures ranging from 0° to 75° F. A total of 438 samples, containing 71,624 eggs, were treated, and approximately 25,000 eggs were observed as control samples. In tests at low temperatures the control samples were divided, one half being exposed to the same temperature as the treated eggs for a similar period, and the other half remaining at room temperature. The results are given in table 7.

When the data were plotted (fig. 11), the increase in the exposure necessary was not a straight-line relationship, but tended to level out below the freezing point. A 30-minute exposure was apparently sufficient at 45° F. and above, but at 36° an exposure of 1¾ hours showed survivors in 3 of 4 tests, although 4 tests with 1½-hour and 5 of 6 tests with 1-hour exposures resulted in complete mortality. The survivors at the 1¾-hour exposures were very few. At 25° there were also a few recoveries in 3 of 8 tests at 1¾-hour exposures. At 10° mortality was complete at all exposures of 1 hour or more. At 0° slight survival occurred in 2 of 7 tests at 2¼-hour exposures. Active lice were also included in several tests to verify earlier determinations that they were more easily killed than eggs. With one exception, they were readily killed with exposures for ¾ hour at 50° and above, for 1½ hours at 41°, for 1¾ hours at 30° and 25°, and for 2¼ hours at 0°.

EFFECT OF EXPOSURE TO COLD ALONE

Samples of louse eggs were exposed at various temperatures ranging from −15° to 42° F. The eggs were little affected until they were exposed to temperatures below 0°. At 36° complete mortality of eggs resulted after exposure for 240 hours, at 25° after approximately 168 hours, at 12.5° after 24 to 44 hours, at 0° after 8 to 16 hours, at −10° after 2 to 3 hours. The tests involving eggs are summarized in table 8.

TABLE 7.—*Hatching of louse eggs exposed for various periods at different temperatures to 20-cc. dosages of methyl bromide in individual fumigation bags each containing approximately 25 pounds of clothing*

Temperature	Exposure	Total samples	Total eggs exposed	Eggs hatched	Fumigation test: Total	Fumigation test: Con...
° F.	*Hours*	*Number*	*Number*	*Number*	*Number*	*Number*
0	1	5	1,438	69	2	
	1½	3	871	0	1	
	2	25	4,275	34	9	
	2¼	14	4,352	47	7	
	2½	9	2,313	0	5	
	2¾	6	1,284	0	3	
	3	5	717	0	2	
	4	4	908	0	1	
10	½	2	367	7	1	
	1	4	700	0	2	
	1½	5	1,006	0	3	
	2	21	3,022	0	8	
	2½	8	1,300	0	3	
	2	3	351	0	1	
12½	3	2	385	0	1	
	4	2	300	0	1	
25	½	4	046	1	1	
	1	4	819	8	1	
	1¼	26	4,339	89	10	
	1½	17	2,606	18	8	
	2	4	044	0	1	
	2½	3	432	0	1	
32	1½	4	1,216	0	2	
36	½	2	651	4	1	
	¾	2	774	134	1	
	1	17	2,863	127	6	
	1¼	13	1,883	0	4	
	1½	[1] 6	972	14	4	
	2	3	350	0	1	
41	¼	16	1,408	3	4	
	⅓	12	830	0	2	
	½	11	674	0	2	
	1	8	1,360	0	4	
	1½	8	956	0	4	
46	½	2	409	0	1	
48	½	2	381	0	1	
50-55	½	6	568	0	4	
	¾	[2] 25	4,206	0	14	
60-64	½	3	283	0	3	
	¾	[1] 10	1,544	0	5	
	Minutes					
65-70	20	11	692	38	2	
	22	11	720	26	2	
	24	11	753	10	2	
	30	44	8,410	0	10	
	45	8	1,100	0	4	
	Hours					
70-75	½	19	2,771	0	12	
	¾	8	624	0	4	

[1] 2 samples consisted of eggs collected from clothing.
[2] 1 sample consisted of eggs collected from clothing.

Active lice were also exposed to low temperatures in some of the tests. Since facilities for feeding the lice were not available, the effectiveness of the exposure was determined by comparing the rapidity of death with that of lice held during the same period at room temperature. They apparently succumbed to shorter exposures than were needed to kill eggs. Minimum exposures for complete mortality appeared to be about 4 to 8 hours at 10°, 1 to 1½ hours at 0°, and 20 to 50 minutes at –10°.

TABLE 8.—*Hatching of louse eggs after exposure to temperatures between –15° and 42° F.*

Temperature	Exposure	Total samples	Samples with no hatching	Total eggs exposed	Eggs hatched	Control eggs: Total	Control eggs: Hatched
° F.	*Hours*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
–15	3	3	3	408	0		
	4	3	3	387	0	354	198
	5	3	3	394	0		
[illegible]	½	2	0	670	186	602	531
	1	1	0	498	44	660	559
	1½	12	10	1,603	102	1,871	1,105
	2	13	11	1,792	38	[illegible]	1,234
	2½	12	11	1,203	2	1,416	674
	3	11	11	1,339	0	919	728
[illegible]	½	2	2	740	0		
	1	2	2	702	0		
	1½	2	2	543	0	752	38
	2	2	2	676	0		
[illegible]	½	1	0	259	41	369	317
[illegible]	¼	1	0	700	78		
	½	1	0	561	124		
	½	1	0	625	152	448	360
	½	1	0	623	59		
[illegible] to –10	43 min.	1	0	208	71	332	206
[illegible]	1	3	1	1,422	34	846	342
	1¼	2	0	703	450	680	639
	1½	2	0	365	120	177	130
	2	11	0	3,166	301	1,477	632
	2½	2	0	215	60	216	161
	3	4	0	805	87	546	342
	4	7	1	769	42	1,207	451
	5	4	0	404	47	172	103
	6	11	3	1,100	45	1,149	513
	6½	1	1	661	0	265	64
	7	4	0	339	14	277	189
	8	11	6	1,347	10	1,149	513
	16	8	6	607	0	358	235
	18	2	1	332	20	240	161
[illegible]	2	8	7	973	15		
	4	12	10	1,242	0	809	185
	6	8	7	1,523	2		
	8	8	8	1,279	0		
[illegible]	5	1	0	103	100		
	6	1	0	215	7		
	17	1	0	135	30	56	80
	20	1	0	136	18		
	25	2	1	305	6		
	48	1	1	57	0		
[illegible]	2	2	0	157	68	177	130
	3½	2	0	213	38		
	8	6	0	665	165	410	231
	16	7	3	465	42		
	21	6	2	907	0	680	316
	44	2	2	315	0	177	130
	48	2	2	216	0	140	79
[illegible]	24	2	0	105	157	235	204
	48	1	0	101	78		
	120	3	1	678	62	670	331
	168	1	0	590	2	336	127
	240	2	2	262	0	237	204
[illegible]	120	1	0	600	88	338	127
	168	1	0	475	17	235	204
	219	2	2	188	0		
[illegible]	120	3	0	262	105	235	201

[1] No control sample.

DISCUSSION

The military forces decided that the high dosage-short exposure combination would best fit their needs. They adopted as standards an ampoule containing 20 cc. of methyl bromide, a bag 25 inches wide and made of material coated with either ethyl cellulose or Neoprene, the fold-over-tie closure, and the special pocket for the ampoule near the top of the bag. Directions for use stipulated that the bag should be laid on its side during exposure.

24

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These decisions were based on the following facts: (1) 20-cc. ampoules would cost little more than 1 or 2-cc. ampoules because labor, not the cost of the contents, would be the determining factor, and bags could be reused with greater frequency with the shorter exposure period; (2) in bags 25 inches wide more economical use of fabrics was made, owing to certain stock widths; (3) the fold-over-tie closure had no detachable parts to be lost; (4) the pocket for the ampoule provided not only that the ampoule would always be located near the top of the bag but also that its position could be easily located from the outside of the bag; (5) fumigation would be successful, even though the bag remained upright, because of the fixed position of the ampoule near the top, should the directions for placing the bag on its side be disregarded.

The following exposure periods for the 20-cc. ampoules were recommended to the Office of the Surgeon General on the basis of partial results:

° F.	Hours
55 and above	$\frac{3}{4}$
45 to 54	$1\frac{1}{4}$
35 to 44	$1\frac{3}{4}$
− 9 to 34	$2\frac{1}{4}$
−10 and below	$2\frac{1}{4}$, to cold alone

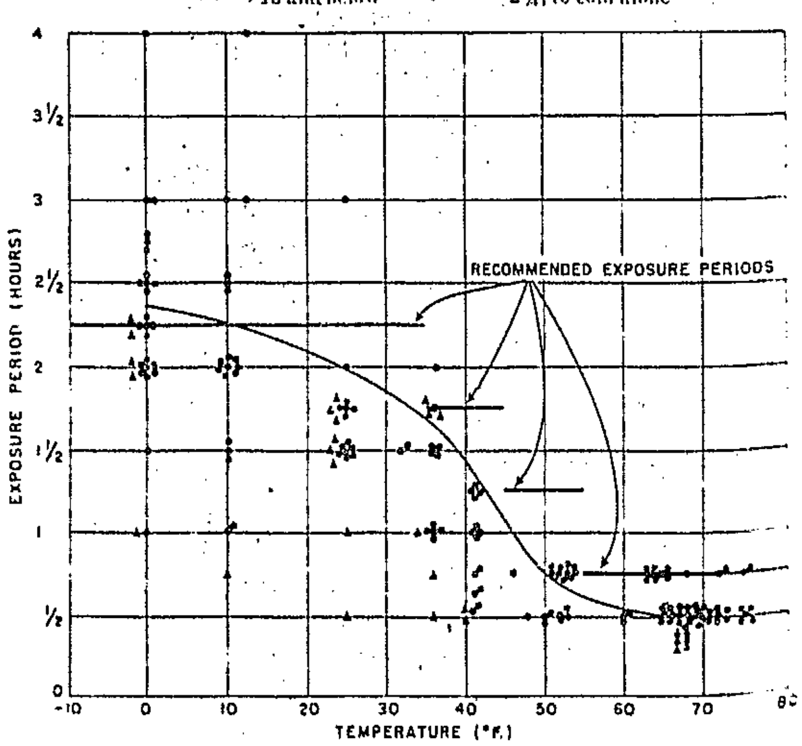

FIGURE 11.—Relation of recommended dosage schedules to the experimental data in table 7. The triangles represent tests giving incomplete mortality and the circles, tests giving complete mortality.

tests, as given completely in table 7, in general supported these recommendations.

The relation of these recommendations to the results of tests are shown graphically in figure 11.

PIT FUMIGATION

Fumigation of louse-infested clothing in ground pits had been suggested as an emergency alternative to vault or individual-bag fumigation. A number of tests were made to determine the feasibility of this method, using dosages similar to those employed in the other methods.

Four types of pits were tested, as follows (fig. 12): (1) An individual pit, holding 1 barracks bag; (2) a trench pit, holding

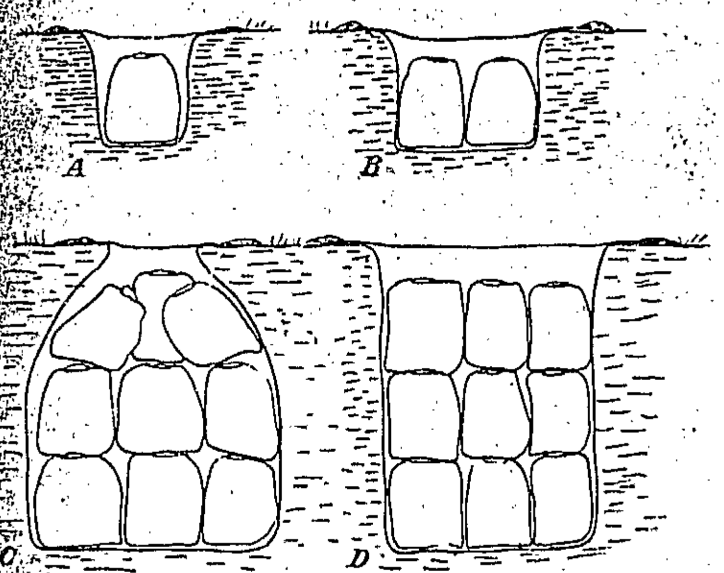

FIGURE 12.—Four types of ground pits used in fumigation tests: A, individual pit; B, trench pit; C, jug-shaped pit; and D, straight-walled pit.

barracks bags side by side; (3) a jug-shaped pit, holding 4 to [illegible] bags; and (4) a straight-walled pit, holding from 20 to 30 bags. The method used in all tests was to dig a pit of the desired size, place the barracks bags in it, cover the opening, and introduce the methyl bromide from ampoules or 1-pound cans. At the end of the exposure period the cover was removed and the bags were immediately lifted from the pit for aeration. They were lifted out of the deeper pits by means of a hook on the end of a short pole.

The ampoules were broken by crushing the tip end with a pair of tongs held at arms length beneath the cover. The broken ampoules were dropped on the top of the barracks bags, the arm was quickly withdrawn, and the cover was sealed at the point of withdrawal.

One-pound cans were opened with the s[illegible]me dispenser as was us[illegible] with the demountable vaults, and the fumigant was emptied i[illegible] the pit through a short piece of tubing (fig. 13).

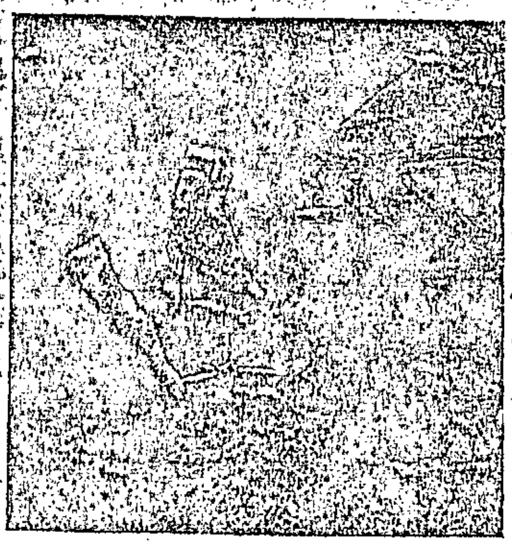

FIGURE 13.—Dispensing methyl bromide from a 1-pound can into a ground p[illegible]

Several types of materials—including duck coated with ethyl cellu[illegible]lose, waterproof-canvas tarpaulin, wrapping paper, newspaper, a lightweight Army raincoat, and boards—were used to cover the open[illegible]ings of the pits. In each instance the cover was sealed by placing a ridge of soil around the margin (fig. 14).

The pits were all dug at the Agricultural Research Center, Belt[illegible]ville, Md., where the soil is a sandy clay with some gravel, and the tests were made under varied conditions of weather and temperatur[illegible].

All samples of louse eggs were from the Orlando colony. The samples were placed both within and outside the barracks bags, with most of them concentrated in the upper part of the pit because the gas concentration would naturally be less in that stratum. Samples were placed in the center of barracks bags, as well as at location[illegible] outside the bags. Fifty tests were made, involving 290 samples with a total of 63,145 eggs. Almost 20,000 additional eggs were observ[illegible] in control samples.

The results, which are given in tables 9–12, show that ground [illegible] are suitable for use in lieu of fumigation chambers or bags, at dos[illegible] comparable to those used in these devices. On calm days high mor[illegible]tality was obtained in small-mouthed pits without a cover, but whe[illegible] wind movement occurred it was necessary to provide a tight cove[illegible] order to obtain complete mortality. Of the covers used, canvas tar[illegible]paulins and boards were the poorest, whereas an army raincoat and duck coated with ethyl cellulose were the best. The size of the open[illegible]ing was also a critical factor, as a few eggs survived in all tests in the

[illegible]ght-walled pit, which had a large opening. The small openings [illegible] the added advantage of being easier to cover (compare figs. 14 [illegible] 15).

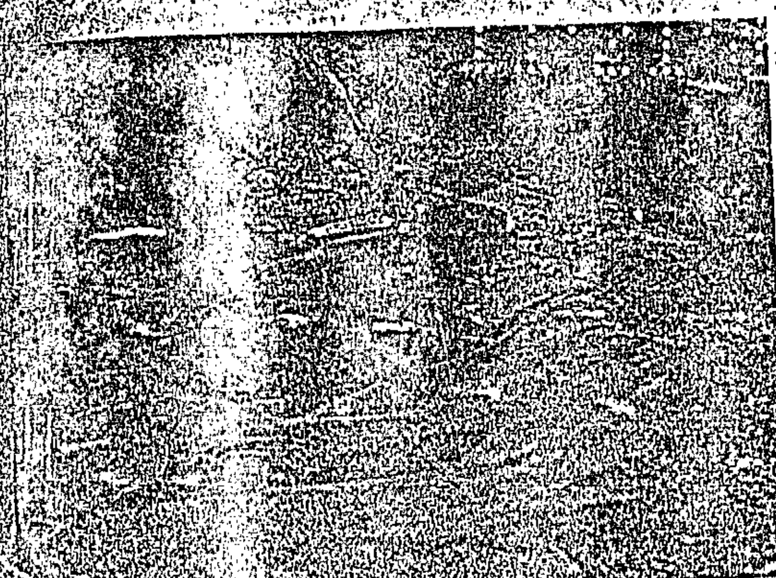

FIGURE 14.—Sealing the edges of a cover on a ground pit.

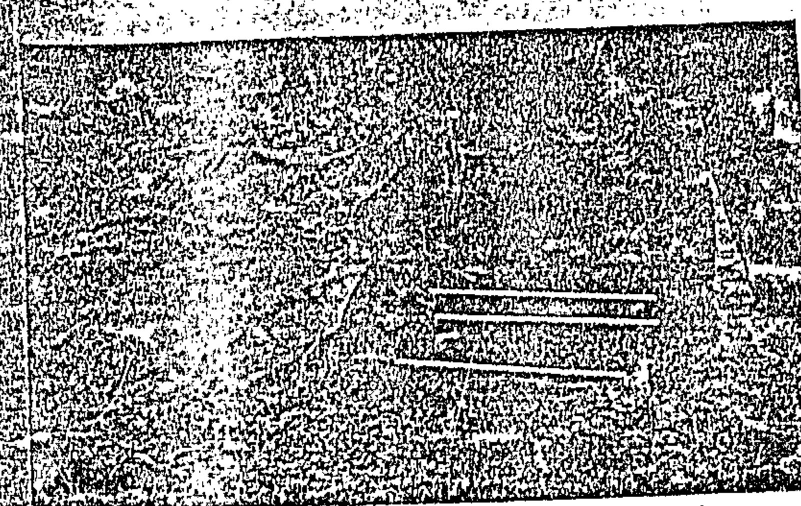

FIGURE 15.—Covering the large opening of a straight-walled pit with supporting strips across the gap.

26

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Dosages of 1 ampoule per bag where 1 or 2 bags were involved, [illegible] ampoules for 4 bags, 4 ampoules for 5 bags, and 8 ampoules for [illegible] bags were satisfactory. For lots of 12 to 21 bags (table 11) a 1-pound can (262 cc.) was sufficient. For lots of 20 to 30 bags in a straight-walled pit (table 12) one 1-pound can did not produce complete mortality, but this was considered to be due more to the character of the pit than to the dosage.

TABLE 9.—*Hatching of louse eggs after exposure to one 20-cc. ampoule of methyl bromide in individual ground pits, with one bag of clothing per pit*

Type of cover	Temperature	Exposure	Total samples	Total eggs exposed	Eggs hatched	Fumigation tests: Total	Fumigation tests: Completely effective
	° F.	Hours	Number	Number	Number	Number	Number
Ethyl cellulose duck	5	2	5	2,005	158	1	
	14	2	5	2,020	0	1	
	37	1½	4	1,646	0	1	
	40–50	1	10	5,016	0	3	
	60–66	½	23	7,923	1	2	
	70	1	4	1,238	0	1	
Canvas tarpaulin	5	2	5	2,038	317	1	
	11	2	5	1,680	118	1	
	37	1½	4	1,705	0	1	
	46	1	4	500	120	1	

TABLE 10.—*Hatching of louse eggs after exposure to two 20-cc. ampoules of methyl bromide in trench pits, with two bags of clothing per pit*

Type of cover	Temperature	Exposure	Total samples	Total eggs exposed	Eggs hatched
	° F.	Hours	Number	Number	Number
Ethyl cellulose duck [1]	62	½	4	464	
Army raincoat	31	3	4	1,379	
	38	1½	4	400	
	55	1	4	1,233	
	55	½	4	870	
Canvas tarpaulin	30	3	4	913	
	40	2	4	1,213	
	40	½	2	647	
Wrapping paper	30	2	4	894	
	46	½	2	[illegible]	
Newspaper	40	1	4	1,812	
	42	1½	4	1,372	

[1] Only one 20-cc. ampoule was used.

AIRING OF CLOTHING

In the preliminary tests it was soon demonstrated that methyl bromide fumes in clothing could be easily reduced to a nonhazardous amount. Clothing removed directly from individual fumigation bags showed a high concentration of methyl bromide trapped between the folds of garments, when such were tested with a halide leak detector,[7] but these pockets were instantly dissipated by shaking the garments. Additional fumes were still absorbed in the clothing, which could be trapped in measurable amounts if the garments were folded again;

[7] A halide leak detector is a convenient instrument for making gross determinations of concentrations of methyl bromide between 50 and 1,000 p.p.m. It is used in the refrigeration industry to detect leaks in refrigerant lines. It operates on a principle of passing fumes of any halide over red-hot copper. If methyl bromide is present, color changes progressing from faint green to dark purple result, and can be used as gross indicators of the concentration.

TABLE 11.—*Hatching of louse eggs after ¾-hour exposure to various dosages of methyl bromide in jug-shaped pits*

Type of cover	Bags per pit	Temperature	Dosage	Total samples	Total eggs exposed	Eggs hatched
	Number	° F.	Cc.	Number	Number	Number
Wrapping paper	4	48	[1] 60	8	2,576	0
	4	64	[1] 60	8	1,900	21
	4	68	60	8	998	1
	4	68	[1] 60	8	1,114	79
[illegible]	5	49	[1] 100	5	500	105
	5	59	80	8	600	9
	5	60	80	6	600	80
	5	77	80	8	800	19
[illegible]	5	49	80	5	500	100
	5	67	50	7	700	11
Army raincoat	10	49	160	10	1,000	0
	12	45	262	8	600	0
	14	48	262	10	1,000	0
	15	55	262	10	1,000	0
	21	48	262	11	1,400	1

[1] Exposure period 1 hour.
[2] Exposure period ½ hour.

TABLE 12.—*Hatching of louse eggs after ¾-hour exposure to a 1-pound dosage of methyl bromide in straight-walled pits*

Type of cover	Bags per pit	Temperature	Total samples	Total eggs exposed	Eggs hatched
	Number	° F.	Number	Number	Number
Ethyl cellulose duck and blanket	20	55	10	2,028	14
Canvas tarpaulin	20	57	10	1,547	11
Ethyl cellulose duck	27	60	12	2,088	12
Ethyl cellulose duck and canvas tarpaulin	30	60	12	1,784	3
Wrapping paper	30	60	12	2,580	15

but if garments were donned, or blankets spread out, the rate of dissipation was such that dilution with air was enough to remove practically all hazard from inhalation.

Further testing demonstrated that if the barracks bags, upon removal from the vault, were placed in a well-ventilated location they would lose practically all fumes within an hour or two, without the necessity of spreading out the contents of the bags.

Thorough tests by the National Institute of Health[8] failed to produce irritation to skin when garments were donned immediately upon removal from fumigation vaults or bags, even when worn in the field by sweating men.

The accumulation of fumes from large quantities of fumigated clothing in closed buildings necessitated special ventilation provisions, which are discussed under Military Utilization of Methyl Bromide.

MILITARY UTILIZATION OF METHYL BROMIDE

The use of methyl bromide fumigation for delousing clothing by the military forces was divided into two general categories—field use, and permanent delousing stations at ports of debarkation.

[8] Unpublished report.

FIELD USE

The armed forces had a very comprehensive program for the suppression of typhus. The program included vaccination of all military personnel to induce immunity, the use of insecticidal powders for personal disinfestation, and fumigation for mass delousing to suppress epidemics. As affairs actually developed, the first two methods prevented any outbreak of typhus among American forces, so that little demand existed for mass delousing in the field. One bad outbreak in the civilian population at Naples was quickly suppressed by wholesale application of insecticidal powders, and marked the advance of this method.

Methyl bromide fumigation, however, was the most potent weapon at hand for mass delousing in the field during the early part of American participation in World War II, until the wholesale application of insecticidal powders demonstrated the potentialities of that method. The Office of the Quartermaster General developed two types of fumigation equipment for field use, based on the original models used in the experimental studies. They were (1) individual bags and ampoules, and (2) demountable vaults.

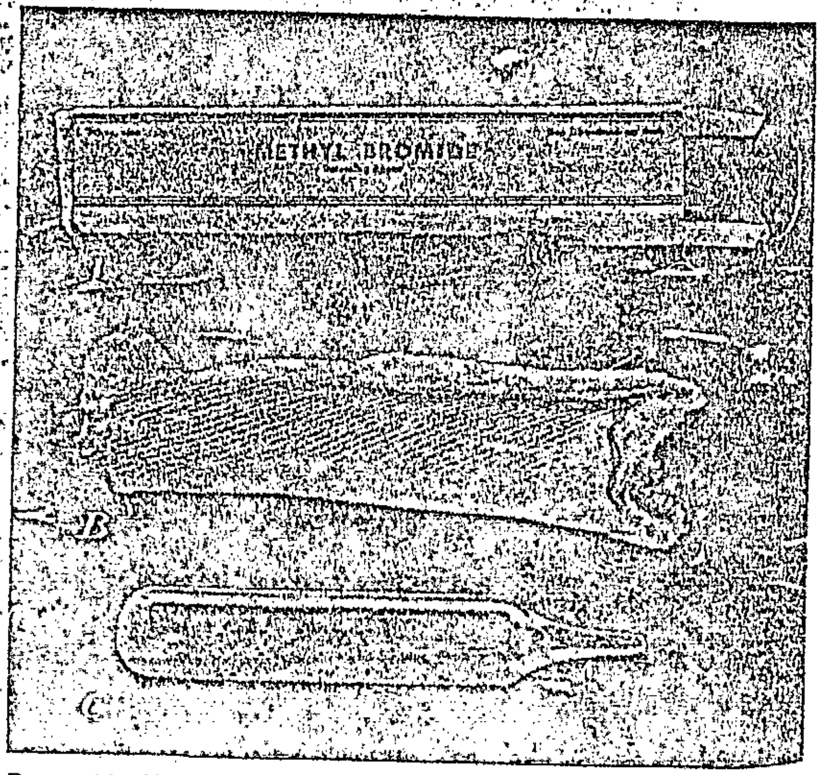

FIGURE 16.—Methyl bromide ampoule produced for military use: A, Individual paper container; B, protective cloth bag; and C, glass ampoule.

INDIVIDUAL FUMIGATION BAGS

[illegible] of its simplicity and because it could be used by the individual soldier, the fumigation bag (fig. 9) was rushed into production [illegible] to accompany the troops that invaded North Africa in the [illegible] of 1942. The first bags were made of sateen coated with ethyl-[illegible] (No. (2), page 21), and used the fold-over-tie closure. The [illegible] cellulose coating was found to have certain drawbacks, one of [illegible] was fusion during shipping, and at the same time it became a [illegible] material because of its use for other purposes. This led to [illegible] development of a double-fabric coated with Neoprene (No. (3), [illegible] 21), which was much better for the purpose. Further production [illegible] with this material. Other materials listed in table 6 were [illegible] at various times in anticipation of a shortage of Neoprene, but [illegible] substitution apparently never became necessary. This bag [illegible] standard Quartermaster item (Bags, delousing, QM 27 B 208).

The glass ampoules of methyl bromide for use in the fumigation bag [illegible] 20 cc. of the fumigant. Each ampoule was placed in a [illegible] protective cloth bag, and packed in individual paper containers (fig. [illegible]). The first production of ampoules was attended by many difficulties, but these were later overcome, and many millions of ampoules [illegible] eventually manufactured. These ampoules were also stocked [illegible] Quartermaster item (Methyl bromide ampoules, QM 51 M 888). The Navy and the Marine Corps also draw this item from the Army Quartermaster depots.

DEMOUNTABLE FUMIGATION VAULTS

The 250-cubic-foot experimental vault (fig. 2) was turned over to the Quartermaster Corps as a model. From this a series of vaults

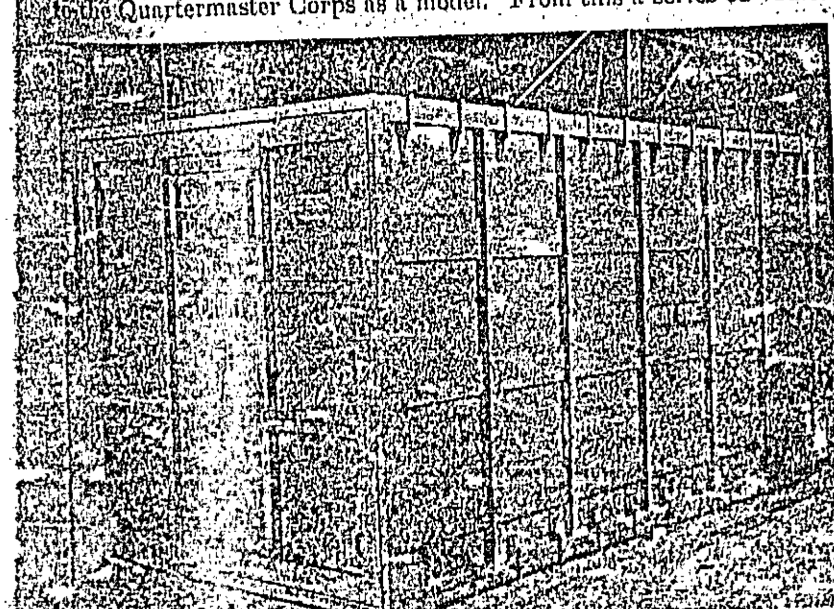

FIGURE 17.—One type of demountable fumigation vault procured by the Army.

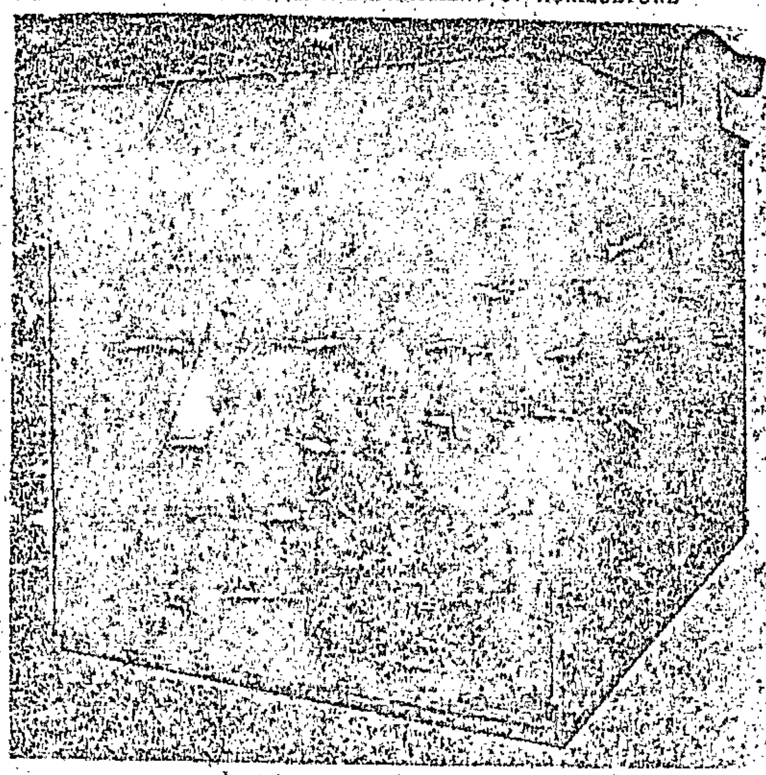

FIGURE 18.—Latest type of demountable fumigation vault procured by the Army

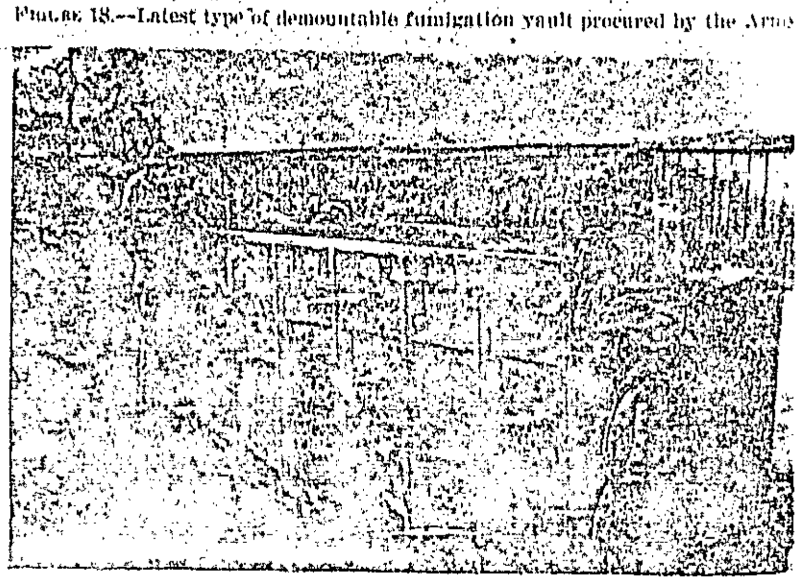

FIGURE 19.—The application of calking compound to the joining surfaces of panels [illegible]

designed and procured, all of which had a capacity of approximately 330 cubic feet and were composed of six panels each—top, bottom, sides, and ends. Each design (fig. 17) embodied the princi-

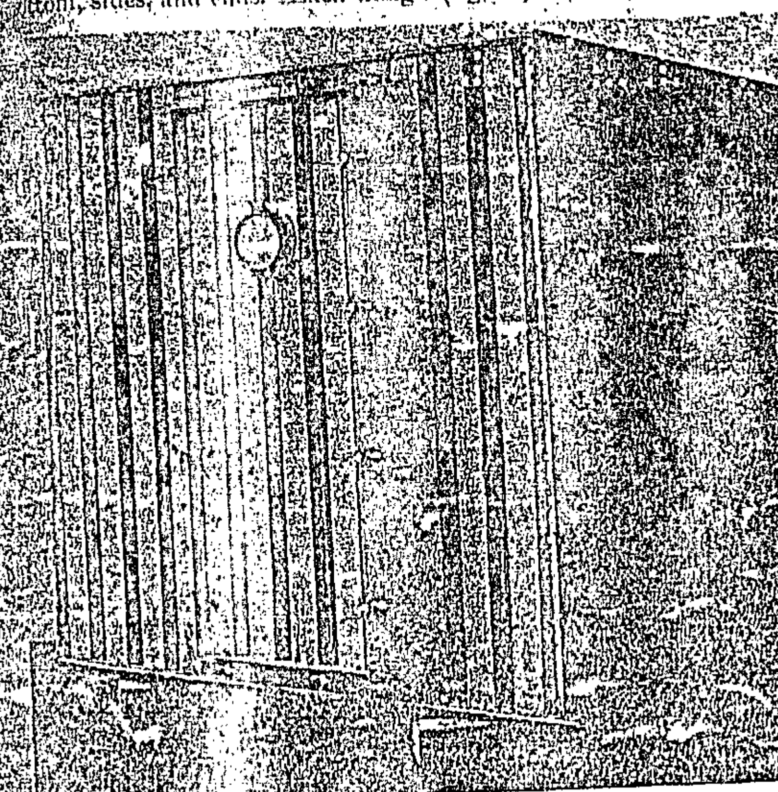

FIGURE 20.—An all-metal demountable fumigation vault used by the Marine Corps.

ples of the original model, except that in the last model an end panel containing a door was used, instead of the whole end panel being used as a door (fig. 18). The use of calking compound (fig. 19) to seal all joints between panels was found to make the vaults gastight with the minimum amount of labor.

These vaults were used by Mobile Fumigation and Bath companies, a number of which were activated as Quartermaster units. A company was composed of 2 platoons, each equipped for independent duty with a battery of 3 demountable vaults, showers, and canvas walks and shelters, and capable of handling from 150 to 300 men per hour. The platoon was set up for operation beside a source of fresh water in a manner to prevent the mixing of infested with deloused men. The men entered a disrobing station, where they removed their packs and clothing and placed them in numbered bags. While the men progressed through showers (heated by an oil-burning portable boiler) and were sprayed on all hairy parts with an ovicidal spray, their clothing and equipment were being fumigated. By the time they reached the end of the line, their clothing was ready for them. By the use of 3 vaults loaded in rotation, a continuous operation could be maintained.

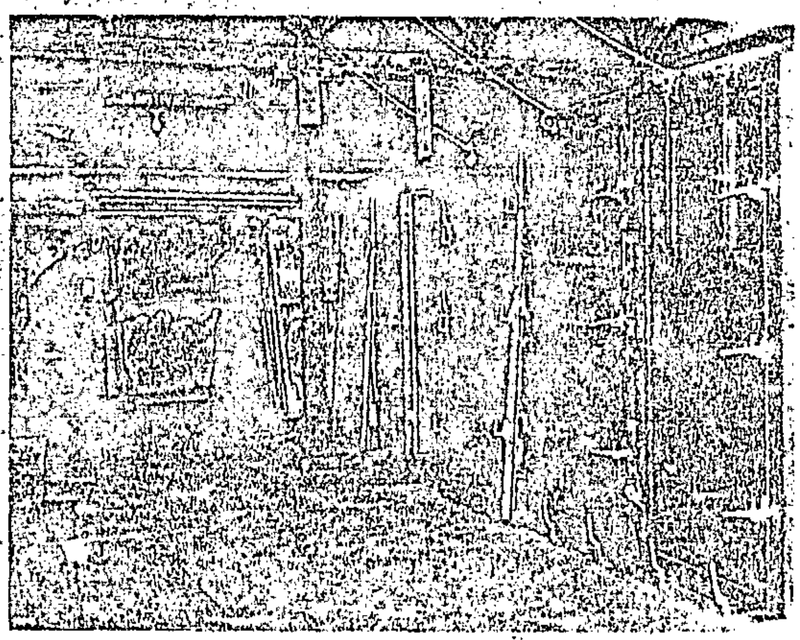

FIGURE 21.—A battery of fumigation vaults in operation at a permanent delousing station at a port in this country. The two vaults in the background are being unloaded, the two center ones are being ventilated prior to unloading and the two in the foreground are under fumigation. (Photo by U. S. Signal Corps.)

A number of demountable vaults of the type shown in figure 18 were procured by the Navy for permanent installation where needed at bases or hospitals. A similar type (fig. 20), but made of steel instead of plywood panels, was procured by the Marine Corps for use by Fumigation and Bath companies modeled after those activated by the Army.

PERMANENT DELOUSING STATIONS

Fumigation of clothing, plus the application of an insecticide spray to the body, has been selected as the most satisfactory method of delousing prisoners of war and personnel reentering the United States from combat zones, to prevent the introduction of typhus-infected lice. This selection was based on the fact that the effect of a fumigation treatment is complete when clothing is returned to a prisoner or soldier at a delousing plant at a port of debarkation, whereas the complete effect of an insecticidal powder can be prevented

its removal, once a louse-infested person is permitted to leave the delousing station.

Permanent delousing stations, with hourly capacity ratings ranging from 150 to 600 men, were built at all 10 of the ports of embarkation and debarkation in North America under Army supervision. The stations were designed by the staff of the Chief of Engineers. Permanent fumigation vaults, of a design similar to that of the experimental demountable vault, were built in batteries at each station (fig. 21). The walls are of concrete or sheet steel with doors of steel, or of wood lined with sheet metal. Several types are illustrated in figures 22–25. At one port an available vacuum-fumigation plant was expanded and utilized which permitted the use of a shorter exposure period. Hundreds of thousands of prisoners of war and military personnel have been treated at these delousing stations.

Each delousing station is laid out so as to prevent recontamination (fig. 26). The personnel to be deloused enter at one point and proceed through various steps, until they leave, without having had contact with persons entering behind them.

Disposal of the fumigant after the fumigation was completed was a more difficult problem in permanent stations than in mobile field units, owing to the accumulation of fumes from clothing brought into dressing rooms. Special shake-out rooms, with forced ventilation to remove the fumes constantly, were installed. All delousing stations now have provisions for keeping the concentration of methyl bromide in the air below 30 p.p.m. at all times.

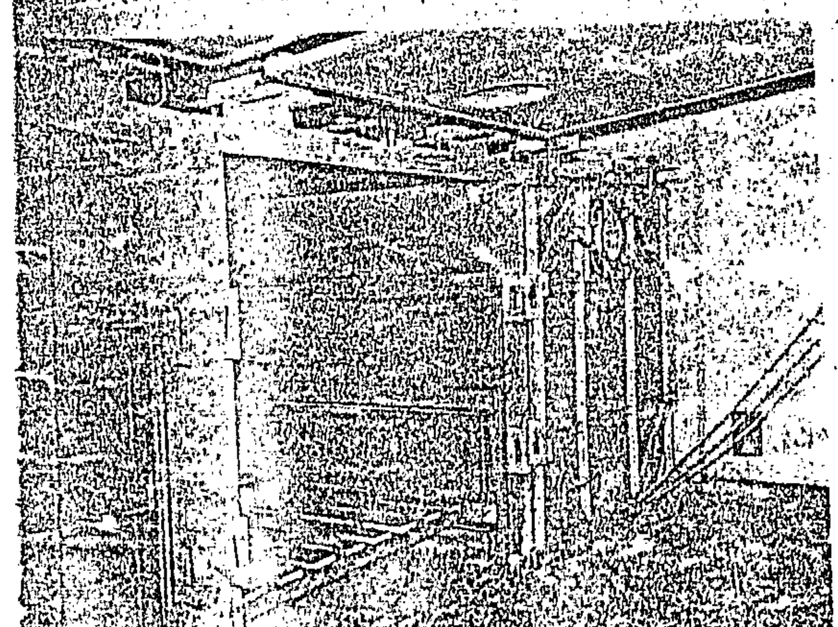

FIGURE 22.—Permanent fumigation vaults, with concrete walls and steel doors, at a delousing station. (Photo by U. S. Signal Corps.)

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1113 PIC Bedbugs Insects (1567)

Studies of Methyl Bromide, Chloropicrin, Certain Nitriles and Other Fumigants Against the Bedbug[1]

HENRY H. RICHARDSON,[2] U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine

The control of bedbugs *Cimex lectularius* L., is particularly important under wartime conditions, since places where numbers of people congregate such as soldiers' barracks and sailors' quarters are favorable for the development of infestations. The likelihood of such infestations in air-raid shelters in England was mentioned by Busvine (1941), and more recent reports (Great Britain Medical Research Council 1942) have confirmed this prediction. Although the bedbug does not seem to have been definitely incriminated as a disease carrier under natural conditions (Hegner *et al.* 1938), the work of Milzer (1942) suggests that it may be an important vector of lymphocytic choriomeningitis (Anonymous 1942).

Laboratory studies have been made of the fumigation efficiency of a number of chemicals, including acrylonitrile (Richardson & Casanges 1942b), 1,1-dichloro-1-nitroethane (O'Kane & Smith 1941), and certain chloroacetonitriles (Peters 1940), that have recently been found toxic to various insects. Methyl bromide, chloropicrin, hydrocyanic acid, carbon disulfide, and 15 other fumigants have also been tested. Approximately 150 fumigations have been made in glass flasks and in a steel cylinder, on approximately 15,000 eggs and 30,000 nymphs and adults of the bedbug. These experiments are discussed in this paper.

MATERIALS AND METHODS.—The bedbugs were reared in the laboratory by methods described by Woodbury & Barnhart (1939) and Campbell *et al.* (1941). The insects were kept at 77° F. and allowed to feed once a week on rabbit. Eggs up to 4 days old, first- to fifth-stage nymphs, and adults approximately 4 to 20 days old were used in the tests.

The chemicals tested are listed in table 1. In general they were of the best quality obtainable commercially, and some were of C. P. grade.

The fumigations were made by direct exposure of the insects to the gas either in a 12-liter glass flask by a method previously described (Richardson & Casanges 1942b) or in a 7.7-cubic-foot steel cylinder. Most of the chemicals, including liquid hydrocyanic acid, were measured under a hood with a micropipette to which was attached a hypodermic syringe lubricated with stopcock grease. Ethylene oxide and methyl bromide were measured with a gas burette in the flask tests, but the larger quantities needed in the steel cylinder were measured in a cooled, graduated glass cylinder.

In the flask tests the insects and eggs on a small piece of cardboard were placed in a shallow glass beaker and quickly lowered into the flask after the gas had been vaporized there. Preliminary tests indicated that it made little difference whether the insects were fumigated in the glass beaker, allowed to crawl directly over the floor of the flask, or placed in the flask and exposed to the lower pressure present during gas vaporization.

In the steel-cylinder tests the insects and eggs, on cardboard, were placed in an organdy-covered Petri dish and exposed directly to the fumigant, or the dish was wrapped in 6 to 8 layers of cotton batting to indicate penetrative efficiency in cotton-containing materials such as mattresses. The chemical was injected from a pipette onto a shallow pan at the top of the cylinder, where it vaporized. A small fan was run at very low speed for the first 10 minutes to distribute the gas. The slight increase in pressure due to vaporization was then relieved. With a number of the more toxic gases some final tests were made under loaded conditions by placing a barracks bag containing a 25-pound unit of clothing and blankets in the cylinder. The barracks bag contained 2 heavy woolen blankets (each weighing about 4 pounds), a heavy overcoat, a suit coat, trousers, a blouse, summer and winter underwear, socks, and shoes. This gave a load of approximately 3 pounds of clothes per cubic foot of space. A sample of bedbugs was wrapped in 8 to 10 layers of each

[1] Early publication accorded this paper because of its war emergency value.

[2] The writer acknowledges with thanks the assistance of Maurice Welr during part of the investigations, and the provision of a colony of bedbugs by F. L. Campbell, of Ohio State University.

31

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blanket. One blanket was exposed directly to the fumigant, and the other was packed in the center of the filled barracks bag. Another sample of bedbugs was wrapped in 6 to 8 layers of cotton batting and placed beside the first blanket.

All fumigations were made for 5 hours at 77°±0.9° F., atmospheric pressure and a relative humidity of from 50 to 95 per cent.

Usually about 100 eggs, 50 nymphs in the second to fifth instars, and 30 adults were used in each test. First instars were included in most of the earlier tests, but their use was discontinued because in general they were found to be less resistant than the older stages. After the fumigation the insects were kept in Petri dishes at near 77° F. The nymphs and adults were examined 1 and 6 days, and in some cases 10 and 20 days, after fumigation. The mortality observed on the sixth day was used in the final determinations, since most of the toxic action appeared to have taken place by that time. As a precaution, moribund insects present at that time were counted as alive although some of them may have died later. Examinations for egg hatching were made 15 days after treatment. Untreated control insects and eggs were checked at intervals during the work, but after 6 and 15 days, respectively, the mortality was generally negligible and no account was taken of it in calculating efficiency.

EFFICIENCY IN GLASS FLASKS.—Most of the chemicals were tested at three to six different concentrations, although some of the less toxic ones were given only one or two preliminary tests. From these results the approximate concentrations to give 95 to 100 per cent kill of the various stages were roughly determined. The 50 per cent, or median lethal, concentration of some of the chemicals was determined, but inasmuch as it cannot be used to forecast the concentration required for 65 to 100 per cent kill (Shepard 1934, Richardson & Casanges 1942a), the emphasis was placed on the latter concentration, which is of major importance in practical control. The data are summarized in table 1.

To most of the fumigants, but especially to ethylene oxide and ethyl formate, the eggs were more susceptible than the nymphs or adults.[1] On the other hand, the eggs were the most resistant to dichloroethyl ether, and in the preliminary tests to trichloroethylene (confirming work reported by Busvine 1941), methylallyl bromide, and 1-nitropropane. The older nymphs were the most resistant stage to most fumigants. The active stages were

Table 1.—Toxicity of various chemicals as fumigants against various stages of the bedbug. Five-hour exposures at 77° F. (25° C.) in 12-liter glass flasks. Chemicals listed in approximate order of toxicity to the older nymphs.

Chemical	Approximate Concentration to Give 95 to 100 Per Cent Kill: Older nymphs	Adults	Eggs
	Mg. per liter	Mg. per liter	Mg. per liter
Hydrocyanic acid, HCN	0.4	<0.4	<0.4
Acrylonitrile, $CH_2{:}CHCN$	3–4	<2.5	2
Chloracetonitrile, CH_2ClCN	3–4	<3	<3
~~Chloropicrin, CCl_3NO_2~~	~~[illegible]~~	~~[illegible]~~	~~<2.75~~
α,β-Dichloroethyl ether, $C_2H_5OCHClCH_2Cl$	5–6	5–6	>6
Acrylonitrile-carbon tetrachloride mixture (1:1 by vol.)[1,2]	7.5	6–7.5	6
1,1-Dichloro-1-nitroethane, $CH_3CCl_2NO_2$	8	<8	<8
~~Methyl bromide, CH_3Br~~	~~[illegible]~~	~~<7~~	~~<7~~
Dichloroacetonitrile, $CHCl_2CN$	10	<8	<8
Trichloroacetonitrile, CCl_3CN	11	8	<8
Ethylene oxide, $(CH_2)_2O$	14	6–10	<2
1-Nitropropane, $C_2H_5CH_2NO_2$[3]	—	—	—
o-Dichlorobenzene, $C_6H_4Cl_2$[3]	—	—	—
Methylallyl chloride (3-chloro-2-methylpropene-1), $CH_2{:}C(CH_3)CH_2Cl$	25–30	<25	<25
Ethyl formate, $HCOOC_2H_5$	30	25–30	<25
1-Nitrobutane, $C_3H_7CH_2NO_2$[3]	—	—	—
Nitroethane, $CH_3CH_2NO_2$[3]	—	—	—
Ethylene oxide-ethylene dichloride mixture (1:8 by vol.)[1]	35	25–30	<25
Tetrachloroethane-trichloroethylene mixture (1:1 by vol.)[3,4]	—	—	—
sym-Tetrachloroethane, $CHCl_2CHCl_2$	35	35	25
Methylallyl bromide (3-bromo-2-methylpropene-1) $CH_2{:}C(CH_3)CH_2Br$[3]	—	—	—
Carbon disulfide, CS_2	37.5	<30	30
Ethylene dichloride, CH_2ClCH_2Cl	>50	>50	>50
Ethylene dichloride-carbon tetrachloride mixture (3:1 by vol.)[1]	>50	>50	>50
Carbon tetrachloride, CCl_4	>50	>50	>50
Trichloroethylene, $CHCl{:}CCl_2$	>50	>50	>50

[1] Figures given are for the combined weight of both chemicals.
[2] On the basis of acrylonitrile only, the figures would be 2.5, 2.5–3, and 2 mg. per liter.
[3] Subjected to preliminary tests only.
[4] Slightly more toxic than tetrachloroethane on the basis of tetrachloroethane content only.

generally used between 4 and 8 days after feeding, as it was found, with chloropicrin, that recently fed insects were less resistant—similar to the findings of Mayer (1934), Busvine (1938), and Gough (1940) with some other fumigants.

Hydrocyanic acid was the most toxic gas, the results being similar to those of Gunderson & Strand (1939) and others.

[1] The fact that the young, and probably more resistant, eggs were used in the tests should also be considered. Gough (1940) found young eggs to be more resistant than older eggs to sulfur dioxide fumigation, and this probably holds true for most fumigants.

32

Acrylonitrile, which had previously been found very toxic to the confused flour beetle (*Tribolium confusum* Duv.) (Richardson & Casanges 1942b), was the next most toxic chemical. It had a slightly delayed action against the bedbug similar to that noted against the flour beetle. That *is*, bedbugs *exposed* to a killing dosage might appear to be affected slightly or not at all at the end of the fumigation, but all would be dead by the next day. Acrylonitrile is a colorless liquid with a boiling point of 78°–79° C., near that of ethylene dichloride, and is used in the synthesis of artificial rubber. It has a disadvantage in being somewhat flammable, but this can be overcome by mixing it with an equal volume of carbon tetrachloride. The addition of carbon tetrachloride also appeared to increase the toxicity, although this compound apparently was nontoxic at these concentrations. For example, in six paired tests with bedbug nymphs at various concentrations, but with each pair having the same dosage of acrylonitrile, the percentage mortalities were as follows:

Acrylonitrile	Acrylonitrile-carbon tetrachloride
0	40
10	37
36	68
58	98
58	88
76	100

Inasmuch as carbon tetrachloride probably acts also as a carrier to give gas distribution, as it does with other fumigants (Farrar & Flint 1942), its addition has several advantages.

The action of acrylonitrile on warm-blooded animals, according to Dudley & Neal (1942), is like that of a typical nitrile. Cleavage of the molecule probably occurs to produce hydrogen cyanide. They found dogs to be much more susceptible than guinea pigs, the minimum fatal dosage in a 4-hour exposure being near 0.24 mg. per liter for the former and 1.38 mg. for the latter. Dudley, Sweeney, & Miller (1942) obtained no definite evidence of cumulative action in repeated exposures to low concentrations (50 to 150 p.p.m.). In an addendum to their paper Neal & Van Oettinger state that acrylonitrile and hydrogen cyanide seem to be of a very similar order of toxicity to warm-blooded animals on the basis of cyanide content. Until further information is gathered, they propose a maximum permissible concentration of 20 p.p.m. (0.043 mg. per liter) for acrylonitrile in an 8-hour exposure. This compares with the present accepted figure for hydrocyanic acid of 20 p.p.m., or 0.02 mg. per liter.

Chloroacetonitrile and the di- and trichloroacetonitrile are sneeze-type, nonflammable gases, recommended in Germany (Peters 1940) for control of bedbugs and other insects. Although chloroacetonitrile appeared to be the most toxic and was similar in toxicity to acrylonitrile, as was found with the flour beetle (Richardson & Casanges 1942), it had the disadvantage of being slow to vaporize. Trichloroacetonitrile, the least toxic of the three, appeared to have some delayed killing action between the sixth and tenth days after fumigation. Busbey *et al.* (1942) have recently found trichloroacetonitrile, to be more toxic than methyl bromide to the California red scale.

Chloropicrin, which showed high toxicity, has been reported as being much less toxic to the eggs than to the nymphs or adults (Bertrand, *et al.* 1919, Gunderson & Strand 1939, Peters 1939). The present data confirm the toxicity figures of Gunderson & Strand for the nymphs and adults, as well as being near though slightly higher than those of Sherrard (1942), but they show the eggs to be much more susceptible. In paired tests at various dosages the mortalities for older nymphs were 40, 45, 51, 55, 58, 60, and 65 per cent compared with 100 per cent kill of the eggs in all the tests except one, where it was 94. The higher toxicity to the eggs was also noted in other tests. Against the nymphs and adults chloropicrin appeared to have some delayed killing action from the sixth to tenth day after fumigation.

α,β-Dichloroethyl ether was among the more toxic chemicals, but it vaporized very slowly. It may be worth detailed study in some phase of bedbug control, such as in spraying vacant houses or *houses that are to be demolished.*

Ethylene oxide was not found so toxic to nymphs and adults as reported by Gunderson & Strand (1939), but the toxicity figures were near those of Busvine (1938). The concentration needed for killing the eggs was only about one-seventh, or less, that needed to kill the older nymphs, these results being similar to

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those of Mayer (1934) and Busvine (1938). The addition of ethylene dichloride to ethylene oxide in a proprietary mixture appeared to increase its efficiency slightly when compared on the basis of equal dosages of ethylene oxide. Ethylene dichloride alone appeared to have little if any toxic effect at these concentrations.

1-Nitropropane seemed to be about as effective against the bedbug as against the flour beetle (Richardson *et al.* 1943). Preliminary tests with 1-nitrobutane and nitroethane indicated them to be less toxic in that order, the results differing from those with the flour beetle.

o-Dichlorobenzene appeared to be similar in toxicity to 1-nitro-propane. Bedbugs fumigated with o-dichlorobenzene became very active and appeared to be much irritated. It is important to note, however, in a report of an English committee on bedbug infestation (Cameron 1942), that o-dichlorobenzene was rejected as a bedbug fumigant or spray because of its danger from the health standpoint.

Methylallyl chloride, which has been recommended as a fumigant in Europe (Briejèr 1938, 1939), was among the less toxic compounds. The closely related compound, methylallyl bromide was less toxic, contrary to results with the flour beetle.

Tetrachloroethane was among the less toxic materials, although more toxic than the closely related compound, ethylene dichloride. It vaporized very slowly at room temperature. A mixture of tetrachloroethane and trichloroethylene has been patented by Balázs (1939) for use against bedbugs. In the present work a 1:1 mixture (by vol.) gave 98, 100, and 100 per cent kill of nymphs, adults, and eggs, respectively, compared with 71, 100, and 100 per cent given by tetrachloroethane tested at the same tetrachloroethane dosage (30 mg. per liter). Trichloroethylene alone at about the same dosage had little if any killing action, but it did have an unusual anesthetic action, for all the insects appeared paralyzed at the end of fumigation but were completely recovered by the next day.

Ethylene dichloride was relatively low in toxicity. Preliminary tests indicated that it had some delayed killing action between the sixth and twentieth days after fumigation, but by no means to the extent it had in previous work against the flour beetle. The addition of carbon tetrachloride did not appear to increase its efficiency. Carbon tetrachloride alone was also among the least toxic chemicals tested.

FUMIGATION EFFICIENCY IN AN UNLOADED STEEL CYLINDER.—Most of the chemicals found to have the highest toxicity in the flask tests were tested three to five times in the unloaded steel cylinder together with two organdy-covered Petri dishes containing insects, one being wrapped in 6 to 8 layers of cotton batting. In general, the gases tested had no difficulty in penetrating the cotton. For example, in five paired tests with various dosages of acrylonitrile and four with chloropicrin the percentage mortalities of the older nymphs were as follows:

Acrylonitrile		Chloropicrin	
Nymphs exposed directly	Nymphs wrapped in cotton	Nymphs exposed directly	Nymphs wrapped in cotton
100	99	97	98
100	100	93	84
97	99	60	66
94	98	45	58
13	25		

Similar results were obtained with chloroacetonitrile, methyl bromide, 1,1-dichloro-1-nitroethane, di- and tri-chloroacetonitrile, ethylene oxide and its mixture with ethylene dichloride, and ethyl formate.

In the case of acrylonitrile, chloropicrin, 1,1-dichloro-1-nitroethane, and methyl bromide, the concentrations required for 95 to 100 per cent kill in the unloaded steel cylinder were approximately the same as those found necessary in the glass flasks. With hydrocyanic acid, chloroacetonitrile, di- and tri-chloroacetonitrile, ethylene oxide-ethylene dichloride mixture, and ethyl formate, however, somewhat higher concentrations were required in the steel cylinder. The reason for this is not known at this time.

FUMIGATION EFFICIENCY IN A LOADED STEEL CYLINDER.—Some of the more toxic fumigants were given preliminary tests in the heavily loaded steel cylinder (8 pounds of clothing per cubic foot of space) to determine the penetrative powers into cotton batting and woolen blankets exposed directly to the gas or packed in the center of a bag of clothing. A uniform dosage of 20 mg. per liter (20 ounces per

1,000 cubic feet) was used. The results are shown in table 2.

The mortality figures indicate that the woolen blanket placed in the center of a bag of clothes furnished the most difficult test of penetration.

These and other tests at dosages of 16 and 18 mg. per liter indicate methyl bromide and chloropicrin to be the most efficient chemicals under the heavily loaded test conditions. They were used at only about 2 and 3 times, respectively, the dosages required to kill in an empty flask or cylinder. On the other hand, hydrocyanic acid at 20 to 30 times the killing dosage gave irregular results and appeared slightly less efficient. Acrylonitrile-carbon tetrachloride mixture at a dosage to give 20 mg. of acrylonitrile per liter, or about 8 to 10 times the killing dosage, was next in efficiency, followed closely by trichloroacetonitrile and 1,1-dichloro-1-nitroethane.

Trichloroacetonitrile at less than twice its killing dosage gave much higher efficiency than chloroacetonitrile used at 5 to 6 times its killing dosage. It is a colorless liquid with a boiling point of 85° C. Its gas is nonflammable. It aerated rapidly from clothing at the temperature tested and might well be considered for further study. Peters (1940) states that it has about the same toxicity to warm-blooded animals as ethylene oxide and methylallyl chloride, but there is little danger of poisoning because of its great warning property. Its vapor is very heavy (sp. gr. 4.95, air = 1).

Ethylene oxide was near chloroacetonitrile in efficiency against nymphs.

In a further test at 18 mg. per liter methyl bromide and chloropicrin seemed to be very close in efficiency. The mortalities of older nymphs caused by methyl bromide were 98.6, 94.7, and 100 per cent in cotton, blanket, and blanket in clothes, respectively, compared with 100, 100, and 93 per cent for chloropicrin. Both gases are practically nonflammable. Chloropicrin has strong warning properties and appeared to have little if any effect on fumigated clothes, but its relatively low vapor pressure might restrict its efficiency at lower temperatures. Methyl bromide has a high vapor pressure and it appeared to have little effect on the clothes or leather shoes under the test conditions maintained.

Table 2.—Efficiency of several fumigants against bedbugs wrapped in various materials to test for penetrative powers under heavily loaded conditions. Dosage, 20 mg. per liter. Five-hour exposures at 77° F. and normal atmospheric pressure.

	Percentage Mortality of Bedbugs Wrapped in—								
	Cotton Batting			Woolen Blanket			Woolen Blanket in Barracks Bag		
Chemical	Older nymphs	Adults	Eggs	Older nymphs	Adults	Eggs	Older nymphs	Adults	Eggs
Methyl bromide	100	100	100	100	100	100	100	100	100
Chloropicrin	100	100	100	100	100	100	100	100	100
Hydrocyanic acid	100	100	100	100	100	100	61.3	90.7	100
Acrylonitrile-carbon tetrachloride mixture (1:1 by vol.)	100	100	100	92.8	100	100	20	25	20.5
Trichloroacetonitrile	94.5	97.5	96.8	75	100	100	64	89.4	98.3
1,1-Dichloro-1-nitroethane	76.0	97.5	78	66.7	97.9	84.3	31.5	67.4	54.3
Ethylene oxide	37.7	—	—	17.8	—	—	24.2	—	—
Chloroacetonitrile	30.6	75	—	1.9	7.3	—	14.8	14	—

SUMMARY.—Twenty-six chemicals or mixtures were tested as fumigants against the eggs, nymphs, and adults of the bedbug (*Cimex lectularius* L.) in 12-liter glass flasks; some of the more toxic chemicals were also tested in a 7.7-cubic-foot steel cylinder. Approximately 150 five-hour fumigations were made at 77°±0.9° F. with approximately 15,000 eggs and 30,000 nymphs and adults.

In the fumigations in empty glass flasks hydrocyanic acid was the most toxic gas. It was followed by acrylonitrile and its mixture with carbon tetrachloride, chloro-

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acetonitrile, chloropicrin, and dichloroethyl ether. Slightly less toxic in the descending order were 1,1-dichloro-1-nitroethane, methyl bromide, di- and trichloroacetonitrile, and ethylene oxide.

The addition of carbon tetrachloride to acrylonitrile (1:1 by vol.) to produce a nonflammable mixture also gave increased efficiency.

Chloropicrin was more effective against the eggs than against the older nymphs and adults.

The second to fifth instars were generally the most resitant and the eggs the least resistant. This relationship varied with some chemicals, the egg being most resistant to dichloroethyl ether and trichloroethylene. The egg was much more susceptible to ethylene oxide. Trichloroethylene had an anaesthetic action against the active stages.

In tests with the more toxic materials in an unloaded steel cylinder the efficiency was just as great against insects protected by cotton batting as against those exposed directly to the gas.

In a loaded steel cylinder methyl bromide and chloropicrin were the most efficient gases when used at a dosage of 16 to 20 mg. per liter (16 to 20 ounces per 1000 cubic feet) against bedbugs wrapped in cotton batting or in woolen blankets exposed directly to the gas, or packed in the center of a 25-pound barracks bag (3 pounds of clothing per cubic foot of cylinder space). Hydrocyanic acid appeared slightly less effective, followed by acrylonitrile-carbon tetrachloride mixture, trichloroacetonitrile, 1,1-dichloro-1-nitroethane, ethylene oxide, and chloroacetonitrile, listed in the approximate order of descending efficiency.—4-5-43.

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Linseed Oil Soap—A New Lure for the Melon Fly

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Fruitfly lures are frequently used in scouting for flies in the field or as a means of following the progress of field investigations. Consequently one of the projects of the Bureau of Entomology and Plant Quarantine includes a search for more powerful lures. This paper records the discovery of the melon fly lure linseed oil soap, experiments to identify the attractive component of the new lure, and some attempts to control the melon fly (*Dacus cucurbitae* (Coq.)) with the lure.

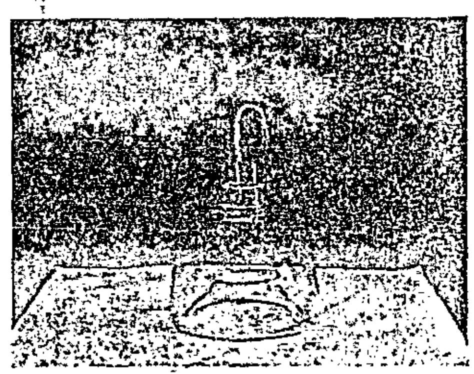

Fig. 1.—Glass trap used for testing lures for the melon fly. Photograph by R. H. Marlowe.

Experimental Trapping Technique.—To compare the response of the melon fly to various materials in the field, Ripley and Hepburn's "method 2" was employed.[1] This method is now standard in the Bureau's fruitfly lure investigations, and is usually referred to as the "reversed-pairs method." It has been extensively investigated statistically, first by Donald F. Starr at the Mexico City laboratory and more recently by Kam Hu Lau and the writer at the Honolulu laboratory. As the name implies, the method consists in pairing control and test traps (usually 4 feet apart) with reversal of position during a second exposure. These traps are illustrated in figure 1.

Some uniformity data by this method are recorded in table 1. In each of these tests 30 pairs of traps were baited with the same lure. One member of each pair was designated the control trap and the other the test trap. The ratios obtained include a maximum error of 16 per cent. The

Table 1.—Uniformity data obtained by the reversed-pairs method of experimental trapping.

Test No.	Number of Flies Caught: Control traps	Number of Flies Caught: Test traps	Ratio Control/Test
1	2,023	2,256	0.90
2	2,207	2,541	0.87
3	2,157	2,377	0.91
4	1,884	2,242	0.84
5	1,618	1,890	0.86
6	1,975	2,016	0.98
7	1,865	1,852	1.01
8	1,592	1,717	0.93
9	1,926	1,985	0.97
10	2,150	2,090	1.03
11	1,877	1,961	0.96
12	1,611	1,609	1.00
13	1,713	1,851	0.93
14	1,447	1,490	0.97
15	1,312	1,226	1.07

[1] Ripley, L. B., and Hepburn, G. A. Studies on reactions of the Natal fruit-fly to fermenting baits. So. Africa Dept. Agr. and Forestry, Ent. Mem. 6: 19–53, illus. 1929.

minimum number ... sure accurate resu... tion. In the prese... pairs, usually 20, ...

The Discover... for insect lures is ... slack proposition; of the discovery ... strong melon fly ...

Since the melon ... centrate on the ... orchid, *Dendrobium* ... was focused on th... experiments, in ... caged flies to blos... blossoms was obse... obtained, but it ... flies only. Experi... lowed.

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Table 2.—Casein h... ponded in traps ove... soap solution.

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Orchard blossoms	1

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[1] The indicated strength ... used in making the soap ...
[2] McPhail, M. Protein lu... 14: 758–61. 1939.

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Rodents

Reference # 2711

Location Selected Counties in California

Number of Replications ________ Plot Size ____________

Time and Date of Application Winter and Fall 1937

Soil Texture Varies

Soil Temperature 30°F – 108°F

Soil Moisture Usually dry

Other Soil Conditions ____________

Crop (Variety) none

Chemical methyl bromide Rate 6 ml – 30 ml / burrow

Method of Application Injection into burrow which was sealed

Many experiments using methyl bromide against rodents were successful.

LVW/lkv; 2/10/78

California

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27(2): 172-180

1938

METHYL BROMIDE AS A RODENTICIDE

By C. E. BERRY, District Supervisor of Rodent and Weed Control,
State Department of Agriculture, Sacramento

IN ADDITION to the damage which they do to agriculture, several species of rodents in California harbor diseases transmissible to humans. Ticks, and fleas or certain other insects, may serve as carriers of these diseases from rodent to human. In rodent control work methods have been employed whereby the rodents have been killed but not always the insects harbored by them.

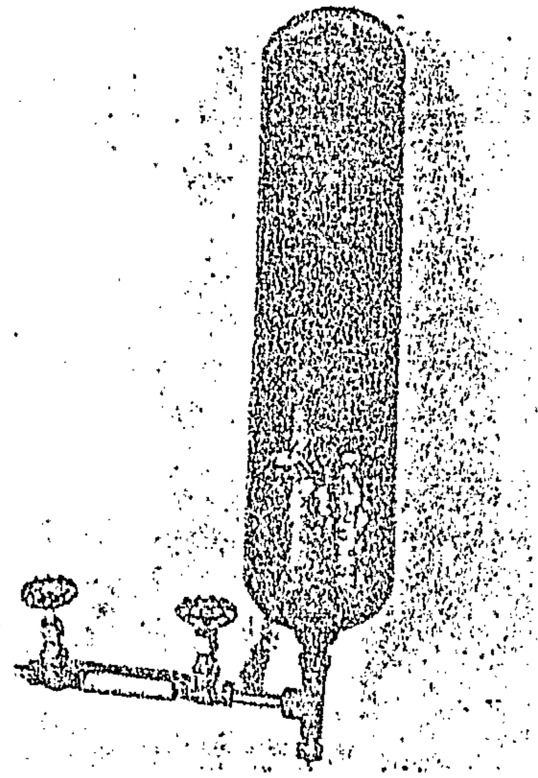

FIG. 1. 2-Globe valves with measuring device between—original applicator.

The results of experiments with methyl bromide in the control of insects by fumigation, conducted by the Entomological Service of the California State Department of Agriculture, led to the belief that this material had double purpose possibilities in rodent control work, and

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Insects

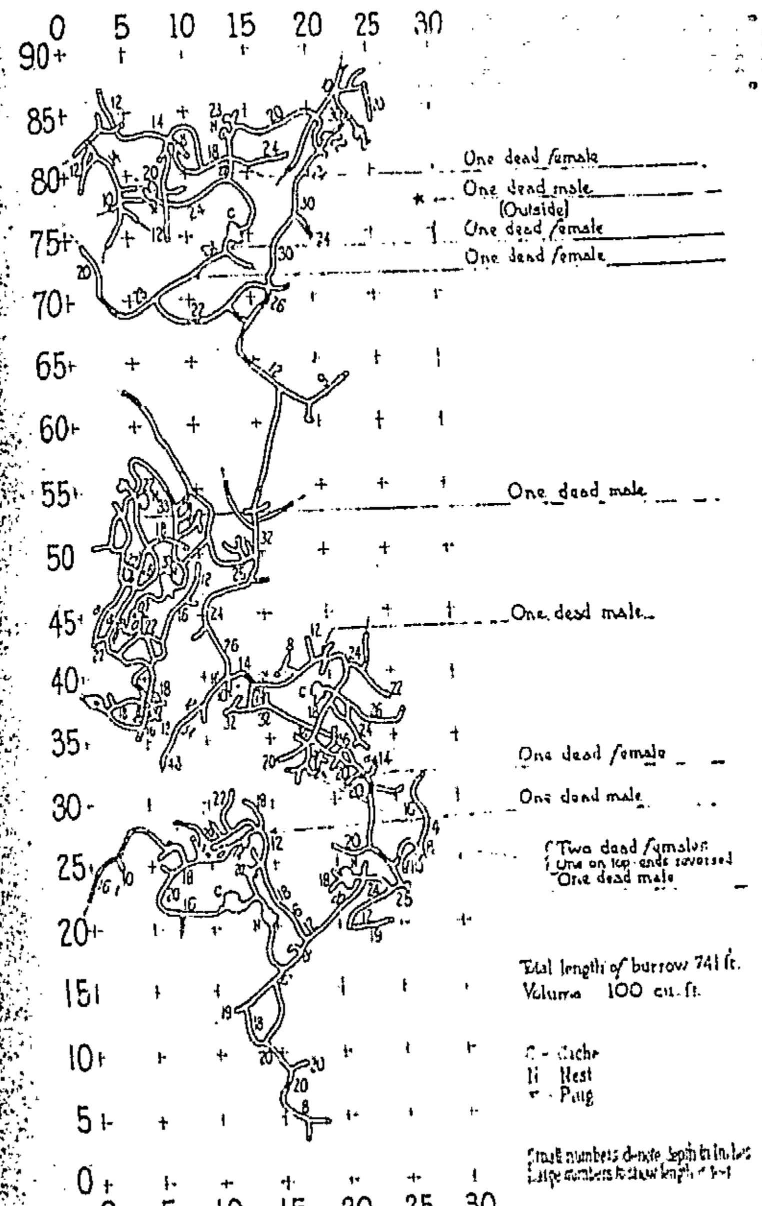

FIG. 2. Diagram. An excavated colony showing ramifications of burrows, with nests, caches and plugged areas.

a period of a little over a year, tests have been made under different temperatures, types of soil, both dry and wet, and in different parts of the State, to ascertain whether these possibilities would work out in field practice.

Methyl bromide heretofore has been used mainly in the manufacture of analine dyes, and in some European countries as a fire extinguisher. It is non-inflammable, colorless and practically odorless. It weighs 14.4 pounds per gallon with a specific gravity of 1.732. The boiling point is about 40.1 degrees Fahrenheit. At ordinary temperatures methyl bromide is a gas, ~~one pound of which occupies 3.95~~ ~~cubic feet~~ and is approximately 3½ times heavier than air. ~~One pound of liquid measures 262 cubic centimeters.~~

The first tests by the department with this material for rodent control purposes were started in Yolo County on November 20, 1936. The soil was of a ~~clay~~ formation, ~~very dry~~ and cracked. Ground squirrels were very active for the season of year. Temperature at time of application was ~~65 degrees~~. The applicator consisted of a small steel cylinder with a measuring device between two Globe valves. (Fig. 1). This applicator was typical of devices which had been used in field trials with a variety of fumigants by the field representatives of the U. S. Bureau of Biological Survey and in cooperation with the Department.

Five hundred and six (506) ground squirrel burrows in Yolo County were treated, and of these all but 60 were closed by filling with soil. Picks were used to provide loose dirt where the ground was too hard for shovels. Fifty-six and three quarter (56¾) pounds of material were used, ~~averaging 30 c.c. per burrow opening~~. On the second day after treatment the uncovered burrows showed 2 active squirrels, and no squirrels where the burrows were closed. The opened burrows were re-treated and closed. ~~One dead squirrel~~ and 1 affected skunk were found at the entrance of two partly opened burrows on the fifth day. The skunk died one hour after being found. The plot was checked daily until the rains of Dec. 12 and no holes were found open. On Dec. 17, 5 burrows were found opened, all apparently from the outside, and at the entrance of two of the burrows were ~~2 dead squirrels~~. There were no signs of any ground squirrel activity elsewhere on the plot, although these rodents were active in adjoining fields.

Five plots were treated east of Delano in Kern County during the period from Dec. 6 to 14, using the same applicator. Temperatures varied between ~~[illegible] degrees and 65~~ degrees Fahrenheit. A 4-foot ⅛ inch copper tubing was used as a connection between the applicator and the burrows. The soil here consisted of ~~sand and clay~~ and was ~~very dry~~. Five hundred fifty-four (554) burrows were treated, using 11¼ pounds of methyl bromide, or an average of ~~[illegible] c.c. per burrow opening~~. Difficulty was encountered when the temperature dropped to 50 degrees F., or below. The material would freeze and plug up the tubing. When the outside temperature approached 30 degrees F the cylinders were heated in a tub of water, and although the gas would freeze as soon as it reached the ground, excellent results were obtained. Over a period of 8 days' checking, ~~only one active ground squirrel appeared on the treated areas, and this was found in a colony~~

~~of 5 burrows where the applicator froze up~~ hence creating a definite uncertainty as to the dosage.

By this time it became apparent that a more satisfactory applicator would have to be perfected. There seemed little doubt as to the value of methyl bromide as a rodenticide, since its volatile character under ordinary temperatures gave adequate pressure to force the material either in the liquid or gaseous form into the interstices of the burrows. The handicap of tube stoppage and leakage were the things indicated for correction.

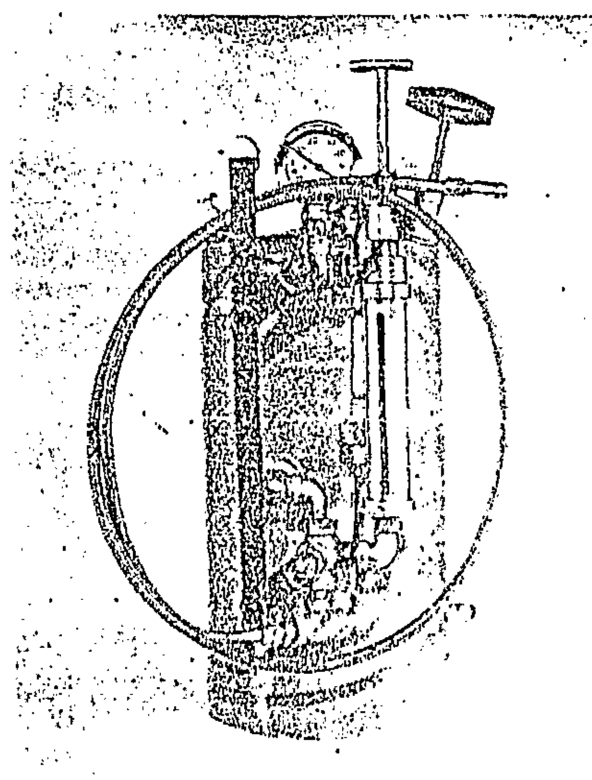

FIG. 3. Mackle-Carter Applicator

Field Tests in San Joaquin County

In these tests the original applicator was used. On Jan. 20, 1937, 6 miles southwest of Stockton, colonies were treated as follows. (1) Three burrows where 3 squirrels were seen to enter. (2) A colony of 7 burrows about 20 feet from the first colony. Approximately 130 c.c. of methyl bromide, or ~~[illegible]~~ were used in these. Time 2 p.m., with outside temperature 50 degrees F. All outlets were closed. 12 c.c.

On Jan. 21, the holes in the above colonies were [illegible] and the burrows dug out with the use of six men from a transient camp [illegible] for through the cooperation of the county agricultural commissioner. All burrows were found plugged with straw and dirt at an average depth of 2½ feet, each plug averaging 2 feet long and about 3½ feet from mouth of burrow. In [illegible] colony ~~[illegible] females~~ were found, each in a separate nest. About 2 feet in front of each nest there was a plug approximately 2 feet long. Three of these squirrels were found in a natural position, as though relaxed and asleep. One was found in a position denoting hibernation. All squirrels showed signs of frothing at the mouth, and a greenish liquid excrement or feces was noted. The nests were at an average depth

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of 3½ feet. Three additional nests were unoccupied. No food caches were found in any of the burrows, although many were buried in the top soil near the burrows.

Samples of the loose soil in the different runways and parts of the nest material, *particularly of the fine particles in the bottom of the nest*, were taken by Dr. M. A. Stewart of the University of California at Davis to determine if the fleas and flea larvae had been killed by the gas. Dr. Stewart reported later that no live fleas or flea larvae were found. Crickets, sow-bugs, flies and California *Prionus* were found dead in the burrows.

On January 22 digging was continued on the second or 7-hole colony. No ground squirrels, either dead or alive, were found. It developed that these two colonies were connected by one tunnel, which was plugged off in two different places. Several nests were found. In the afternoon of the same day there was located a colony in the same field where 5 squirrels were observed entering, and this was treated with methyl bromide, closing all of the 76 holes, using approximately 13 c.c. per hole. The temperature was 80 degrees F. The area covered by the colony was 40 feet wide at one end, 30 feet at the other, and 85 feet long.

On January 25 the holes of the 76-hole colony were uncovered at 8 a.m. A trench was dug 4 feet deep, 3 feet wide, and 40 feet long adjacent to the 40-foot side of the colony. Twelve transient laborers were used, six on the trench side and six on the opposite, or north end. A very intricate system of burrows was found on the trench side. Runways were at a depth of 2½ to 3 feet in one system, with another set below a sort of hardpan soil at a depth of 3½ to 6 feet. Nests were found in both systems, which were connected in many places. Plugged runways were found mainly in the upper system. The system on the north end was shallow; *in fact, no runways were found below the 2-foot level for a distance of about 30 feet.* Five dead squirrels (4 females and 1 male), were found at depths of 2½ to 4 feet. The females were found in or near the nests and the male in the runway near the entrance. Two of the females were plugged in; the male was not.

Digging was continued the next day, January 26, and two dead squirrels were found, 1 male and 1 female. The male was in a nest in the hibernating stage, and was plugged off from the main runway for about 2 feet with dry soil and straw. The female was found in the runway just outside a nest.

Merced County Field Tests

In making excavations in Merced County, through the cooperation of the agricultural commissioner's office, men were made available either from the commissioner's staff or from a National Youth Administration (N.Y.A.) project operating under the sponsorship of the commissioner's office.

Plot 1. Two miles west, 1 mile north of El Nido. *Feb. 16, 1937, 3 p.m.* Temperature 64 degrees F. Soil 52 degrees F., 18 inches deep. Four burrows were treated with 20 c.c. bromide per hole; 2 squirrels were observed before treatment. All of the burrow entrances were closed by filling with earth.

Feb. 17 digging started at 1 p.m. All holes unopened; 2 were plugged about 2½ feet from opening. Hardpan was found from 2½ to a 4 foot depth. Two nests were found at a 2½ foot depth on top of hardpan. Two dead squirrels 1 male and 1 female, were found in open runway, both in normal positions.

Plot 2. Same ranch and temperature as Plot 1. Feb. 16. Seven holes were treated at 3:15 p.m. with 20 c.c. bromide; all holes closed. No squirrels observed, although surface of burrows showed fresh working.

Feb. 17 all holes were still closed. Digging started at 11:15 a.m. A complete system found above hardpan at a depth of 18 inches to 2½ feet. No nests. Another system, with 3 nests, was found under the hardpan from 3½ to 7 foot depth, almost parallel to the upper system. Two old plugs were found near the nests, but no squirrels were in evidence.

Plot 3. —Feb. 16, 3:30 p.m. Same ranch and temperature as plots 1 and 2. One squirrel observed prior to treating 6 holes with 20 c.c. bromide. All burrow entrances closed.

Feb. 17, 11:30 a.m., started digging. Two nests were found at 2½ and 3½ foot levels. One female was found dead behind a 2-foot plug 3½ feet from opening. The plug apparently had just been made and the squirrel died while plugging. One male was found in main runway 3½ feet deep and 15 feet from opening near a nest. It showed some life, but died in a very few minutes after being brought to the surface.

Plot 4. —Ditch Company land, 3 miles north, 1½ miles east of Amsterdam. Feb. 17, 11 a.m. Treated 38 holes with 10 c.c. bromide each. Temperature 62 degrees F., soil 50 degrees F. at 20 inch level. Two squirrels noted immediately prior to treating.

Feb. 18, 9 a.m., started digging. Two holes had been opened, one dead male squirrel partly eaten by a hawk was lying 10 feet from opening. The soil was very *sandy to a depth of 8 feet, where hardpan was found.* A dead male and a dead female were found in nests; 1 female was definitely in a hibernating position; the other in the same position except for the tail, which might have been disturbed in digging. A total of 5 nests was found, one eight feet deep, the balance about 4 feet deep. One dead female was found in an open runway six feet from the opening, making a total of 4 dead squirrels in the colony. Plugs were found in several of the runways and 2 holes were plugged about 2½ feet from the surface.

Plot 5. —Ditch Company land 3 miles north, 1½ miles east of Amsterdam. Feb. 17, 1937, 11 a.m. Temperature 62 degrees F., soil 50 degrees F. at 2 foot level; 15 c.c. methyl bromide used; 44 holes treated; 4 squirrels observed. (Fig. 2.)

Feb. 19. Two holes found open. A group of 20 holes only was dug out of the 44 treated; 2 dead squirrels were found in the same burrow, one about 12 inches below the closed hole and the other 4 feet lower, behind a 12 inch plug. One dead male was found in a nest located 9 feet deep under a rocky formation 2½ feet thick.

It was impossible to finish the digging on account of the depth of the tunnels and the rocky formation.

Reports from Dr. M. A. Stewart at Davis, to whom dead squirrels from Plot 1 and Plot 3 were sent, indicated no live fleas or flea larvae.

In the meanwhile, D. B. Mackie and W. B. Carter of the Entomological Service of the Department developed and constructed a new type of applicator designed to give a measured dosage of methyl bromide. (Fig. 3). The results up to this time had indicated that a smaller dosage would probably serve and a standard of 10 c.c. per burrow opening was deemed proper. The new applicator was built with a three-way opening and discharge valve to permit one complete up and down throw of the handle to allow (a) the liquid to enter the measuring gauge chamber, (b) divest the measuring gauge chamber of its charge, and (c) restore the valve openings to a closed position. Shortly after the development of the above applicator, one of the concerns distributing methyl bromide developed an applicator (Fig. 4)

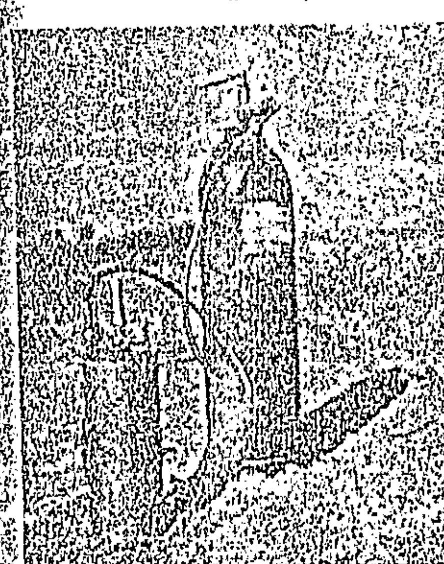

Fig. 4. 3-way 2-port commercial applicator being refilled.

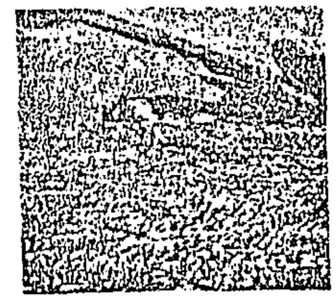

Fig. 6. Squirrels dead from methyl bromide are generally found in above posture.

based upon principles similar to the Mackie-Carter device, but with most of the mechanical operational features enclosed within the cylinder. We can refer to this as the commercial applicator.

Every effort was being made to attain a perfection in applicator construction to obviate leakages of valves or connections to avoid any hazard to operators. The spring and summer period required other rodent work to be done, leaving the methyl bromide tests until fall, when they were resumed in Merced County with a new series of plots.

Sept. 16, 1937. Ten miles west of Merced (Plot I). Treated 168 holes, colony and area, and observed some 14 squirrels. Temperature 105 degrees F. 3:00 p.m. Used 2 different commercial applicators of the same style with 7 pounds of methyl bromide in each, yielding 69 doses out of one and 99 out of the other. Used Mackie-Carter applicator on 14 holes in same plot. One squirrel emerged, was captured and died 22 hours later. Fall 1937

Sept. 17. Started digging Plot I. Recovered 1 dead females and 2 males. Treated Plot II, 88 holes, adjacent to Plot I. Mackie-Carter applicator, 8 c.c. per hole, 4 p.m., to 5 p.m., 104 degrees F. High temperature apparently affects the ability of the applicators to deliver a uniform dosage.

Sept. 18, dug 6 colonies where 6 c.c. shot were applied on Sept. 17. All holes shallow and small colonies. Recovered 1 dead skunk and 1 dead female squirrel.

41

Sept. 20 used commercial applicator, 7 pounds net, to treat 173 holes east of Dallas Ranch, Plot III. Temperature 85 degrees F., 10:15 to 11:35 a.m. Started digging Plot III (sand plot) 1:30 p.m.; at 3:30 p.m. treated Plot IV (salt grass) 33 holes 10 c.c. each, temperature 110 degrees. Eight squirrels observed (4 went down 1 hole), and one cottontail. Holes were closed.

Sept. 21 dug Plot IV, 9 a.m. One squirrel emerged from a treated hole, was captured and died 2 hours later. Recovered ~~3 dead males, 5 dead females and [illegible] cottontail.~~

Sept. 22 continued digging Plot III. No dead squirrels were found. Intricate system 5½ feet in depth was found. Due to sifting sand was unable to continue mapping.

Sept. 23 dug 3 small colonies adjacent to Plot III. ~~Three dead cottontails and 1 dead male squirrel~~ were recovered. Digging not completed.

Sept. 23 at Dallas Ranch, south of ranch house (Plot V) 18 squirrels observed on Sept. 22, on pasture land and 2 tin can dumps adjacent to old hay stacks. 263 holes treated and closed; 133 shots of Mackie-Carter applicator to 7 pounds of bromide; 130 shots of commercial applicator to 7 pounds of bromide. Temperature 75 degrees F. Shot 10 a.m. to 11:05 a.m.

Sept. 23 on Mudd Ranch 5 miles east of Merced, 4:30 p.m., treated open hole; 81 shots (3½ pounds) with Mackie-Carter applicator. Seven squirrels observed at 5 p.m. on Sept. 22; 12 squirrels observed 8 a.m. on Sept. 23, on canal bank, in fig orchard and wood pile.

Sept. 24 checked Mudd Plot at 7:30 to 8:45 a.m. One sick squirrel observed on levee; 10 live squirrels observed in wood pile. Checked Plot V; 1 live squirrel observed.

Sept. 25 Mudd Ranch plot checked at 8:30 a.m. Two live squirrels on wood pile, none on levee.

San Luis Obispo County Field Tests

Assistance was rendered by the county agricultural commissioner, his staff members, and by students from the State Polytechnic School, in excavating burrows and helping generally in the field tests.

From Sept. 29 to Oct. 5, 1937, 4 plots were treated and 3 excavated in several different areas in San Luis Obispo County. In Plot 1, 7 miles east of Morro Bay, 11 burrows were treated ~~and 4 dead females and 5 dead males were~~ found on excavation; ~~10 c.c. bromide~~ were used at each burrow. Treated at 9:15 a.m., temperature 70 degrees F. Many small caches were found, one at a depth of 50 inches. The soil was heavy adobe, very dry and cracked. Plot 2, in the same field consisted of 17 burrows, which were treated with ~~10 c.c. bromide~~ each at 9:30 a.m. On excavation ~~2 dead females and 1 dead male squirrel and 1 dead female gopher~~ were found. As in the above plot, numerous caches of clean oats were found. The Mackie-Carter applicator was used on both plots. The balance of the field was treated with methyl bromide and all holes closed. Thallium-treated oats were used outside of these gas-treated areas. ~~All fleas noted on dead animals and in nests~~ were dead.

On Oct. 2, 1937, a plot 1 mile north of Avila, consisting of 33 holes, was treated and all holes covered; ~~10 c.c.~~ of methyl bromide per burrow were used. This colony was excavated and dimensions taken. (Fig. 4.) The total length of the colony tunnels was 741 linear feet, giving a total displacement of 100 cubic feet of dirt. ~~Three dead males and 2 dead female squirrels were~~ found at depths of 18 to 36 inches. Plugs of dirt and straw were found throughout the system. Numerous caches of barley and many old and new nests also were found.

Another plot consisting of 65 burrows 8 miles west of San Luis Obispo, in a pasture and grain land, was treated on Oct. 6; 10 c.c. of methyl bromide per burrow were used; ~~[illegible]~~ temperature 70 degrees F. at 4 p.m. Observations of the area on 5 separate days over a month showed 2, 4, 6, 3 and 4 active squirrels respectively.

While in San Luis Obispo, Professor Knott of the California Polytechnic School suggested using two 2-way valves synchronized with a measuring cylinder for dosage between the valves; this was tried out; a 3-way 2-port valve with measuring device attached also was tried. Both ideas proved correct dosage could be maintained, but difficulty arose when we were unable to get a valve that would not leak.

Yuba County Tests

In Yuba County on October 27, 1937, one plot of 50 burrows was treated on a steep levee bank adjacent to a row of large English walnut trees. ~~[illegible]~~ dosages were used, applied through a 3-way 2-port valve applicator. Later observations showed no activity. The same day 110 burrows were treated in an almond orchard. The following day no holes were found opened, although one hole had been missed and one dead and 1 affected female squirrel found near the opening. The affected squirrel was killed and the lung cells found to be broken down with the entire pleural cavity filled with blood and body fluid.

Santa Cruz County Field Tests

Aided by the county agricultural commissioner and his inspectors, during the period from Oct. 16 to 20, 1937, 2 plots were treated 8 miles west of Watsonville and excavated. The 3-way 2-port valve applicator was used. Weather fair, temperature 80 degrees F., soil sandy but very dry and hard. One dead male squirrel was found in one plot and one dead female in the other. In Plot 1, 1 salamander, 1 spider, 1 flea and 3 ticks were found at a depth of 43 inches, all dead. In an old nest plugged off, nine lice (*Neohaematopinus laeviusculus*) and 1 tick, all alive, were found.

In plot 2, 32 millepedes, 2 carabid beetles, 1 graph moth, 1 [illegible], 1 scorpion, 1 sow bug and 1 spider were found dead in nests. Seven caches, each holding about 1 quart of oats, were found off the main runway at a distance of about 3 feet and at a depth of 48 inches. Another cache contained more than a gallon of oats about 3 feet farther on in the same runway.

On a plot near the San ~~[illegible] 1 male and 1 female squirrel, 1 salamander and [illegible] were found.~~ The dosage was 20 c.c. methyl bromide; 8 holes were treated. Both double 2-way and single 3-way valve applicators were leaking badly, so the dosage probably was actually between 10 and 15 c.c. per burrow.

Santa Clara County Field Tests

A plot in Santa Clara County, adjoining the State College stadium, consisting of approximately 100 acres, was treated on a clean-up basis. A total of 4451 holes was treated with 9.3 c.c. methyl bromide each, using a 3-way 2-port commercial applicator. (Fig. 5.) After treating 2500 holes, the valves began to leak. No squirrel activity was noticed on the first 2500, but from 2500 to 3500 about 40 holes had to be retreated. After the 3-way valve began to leak, two 2-way acetylene valves were used; these leaked before the plot was finished. Several squirrels dug out and were found dead on the surface. (Fig. 6.). A total of 151½ pounds of methyl bromide was used.

Effect of Methyl Bromide on Rats

In spite of the fact that it had been impossible under field conditions to observe the effects of methyl bromide on ground squirrels, some idea can be gained of the effects of the material on rodents, through observations made on rats by D. B. Mackie and W. B. Carter of the Entomological Service. These observations were made in the laboratory under conditions simulating a burrow by utilizing a large glass jar. These observations follow:

RAT No. 1—Adult Female

Weight—12 ounces.

Dosage—CH_3Br, 1 cc per cu. ft.

1st min.—Signs of drowsiness apparent, head drooped, eyes half closed.

5th min.—Powers of locomotion impaired. Respiration rapid; breathing, spasmodic; 3 seconds rapid and 6 seconds slow. Lying on side. Fecal matter deposited (considerable).

6th min.—Pulsations change from 3 seconds rapid and 6 quiet to 3 and 3.

8th min.—Respiration very irregular and rapid. This condition continued to 42 minutes, when, without slowing down, heart action stopped.

42d min.—Dead.

Both urine and fecal matter were discharged during period. There was also mucous discharge from nose and mouth and a watering of the eyes.

RAT No. 2—Adult Male

Weight—13 ounces.

Dosage—CH_3Br, .5 cc per cu. ft.

1st to 5th min.—Rat walked back and forth, showed no signs of noticing gas. No agitation. Smelled various parts of jar.

9th min.—Head began to droop and eyes half closed. Signs of drowsiness. Quietly sitting at end of jar. Shows evidence of nervousness.

13th min.—Several spasmodic breathing spells in nature of short gasps.

20th min.—Telephone bell awakens from lethargic state. Walks length of jar —3 feet—locomotor nerves affected.

31st min.—Eyes watering slightly, glassy look, seemingly drowsy or lethargic.

81st min.—Breathing spasmodic with periodic gasps. Lying on side

93d min.—Breathing spasmodic and rapid succession

103d min.—Moved head slightly. Eyes blinking at irregular intervals. Makes effort change position. Legs seem paralyzed. Moves head slightly.

114th min.—Breathing irregular and spasmodic gasps. Nose twitches slightly, blinking of eyes more noticeable. Discharge nose and mouth.

128th min.—Convulsions of abdominal muscles about every 36 seconds.

143rd min.—Convulsions increasing in rapidity but not intensity, more erratic.

145th min.—Breathing ceased and death occurred

Both urine and fecal matter were discharged, the latter during first hour, former during latter part, seemingly due to paralysis of controlling muscles

In order to be certain that material of a character as lethal as methyl bromide is surrounded with adequate safeguards, all further 42 tests have been postponed until greater assurance can be developed that applicators and appurtenant valves and connections will not leak and subject the operator to an unwarranted hazard. It is intended also to determine whether or not a warning feature can be attached to methyl bromide through the addition of something pungent or acrid in character to serve as a tracer material.

CONCLUSION

Methyl bromide has proved to be effective in the control of rodents as well as the insects harbored by them. There is no danger from fire. It can be used in wet or dry soils and at various temperatures. Although at present the cost is high, it can be used where follow-up or eradication measures are being carried on and around buildings where there is danger in using treated grain baits. It should be used only under proper and adequate supervision even by official agencies having a trained personnel, and should not be made available for general use until further safeguards have been conclusively developed.

ACKNOWLEDGMENTS

Appreciation is expressed for the collaboration of C. Olsen and E. Johnson of the Rodent, Plague and Weed Control Service and Joseph Keyes of the U. S. Bureau of Biological Survey in conducting the field tests and in the preparation of notes and tabulations in this article; also for the valuable assistance received from the Entomological Service of the Department, the county agricultural commissioners, staff members in zoology and entomology from the University Farm at Davis, the California Polytechnic School at San Luis Obispo and other participating agencies.

Reference # 1685

Location University of Connecticut, Storrs, Connecticut

Number of Replications ________ Plot Size ________

Time and Date of Application ________

~~Soil Texture~~ ________

~~Soil~~ Temperature 32 °F

~~Soil Moisture~~ ________

~~Other Soil Conditions~~ ________

Crop (Variety) ________

Chemical Methyl Bromide (100%) Rate 0.25, 0.5, 1.0, 2.0, 4.0 lbs/1000 ft^3

Method of Application Probably in evaporating dishes

TABLE I—THE EFFECT OF VARIOUS CONCENTRATIONS OF METHYL BROMIDE ON THE SURVIVAL TIME OF WHITE RATS AT 32 DEGREES F

Treatment (Pounds per 1,000 Cubic Feet)	Sex	Average time to kill (Minutes)
0.50	Female	190
0.50	Male	212
1.00	Female	146
1.00	Male	160
2.00	Female	110
2.00	Male	135
4.00	Female	76
Control	Female	Not dead after 4 hours at 32 degrees F
Control	Male	Not dead after 4 hours at 32 degrees F

TABLE II—THE EFFECTIVENESS OF METHYL BROMIDE IN KILLING RODENTS IN A SMALL STORAGE ROOM AT 32 DEGREES F

Trial	Treatment (Pounds per 1,000 Cubic Feet)	Species	Number of Rodents	Age	Per Cent Mortality	
					After 4 Hours	After 2 Days
1	1 pound for 4 hours + air circulation	White mice	6	Juvenile	100.0	100.0
		White mice	3	Adult	100.0	100.0
		Meadow mice	4	Adult	100.0	100.0
		Pine mice	1	Adult	100.0	100.0
		White rats	6	Juvenile	100.0	100.0
		White rats	6	Adult	100.0	100.0
2	¼ pound for 4 hours + air circulation	White mice	4	Juvenile	100.0	100.0
		White mice	5	Adult	100.0	100.0
		Meadow mice	3	Adult	100.0	100.0
		White rats	5	Juvenile	100.0	100.0
		White rats	9	Adult	55.6	100.0
3	¼ pound for 4 hours no air circulation	White mice	3	Adult	100.0	100.0
		Meadow mice	2	Adult	50.0	100.0
		Wild rat	1	Juvenile	100.0	100.0
		White rats	3	Juvenile	0.0	100.0
		White rats	5	Adult	0.0	100.0
4	Control	White mice	3	Juvenile	0.0	0.0
		White mice	4	Adult	0.0	0.0
		Meadow mice	2	Adult	0.0	0.0
		White rats	2	Juvenile	0.0	0.0
		White rats	6	Adult	0.0	0.0

44

TABLE III—THE PER CENT MORTALITY OF RODENTS PLACED IN A COMMERCIAL COLD STORAGE AND SUBJECTED TO VAPORS OF METHYL BROMIDE AT 32 DEGREES F

Treatment (Pounds per 1,000 Cubic Feet)	Species	Number of Rodents	Per Cent Mortality After 6 Hours Treatment
¼ pound for 6 hours	White mice	16 adult males	100.0
	White mice	10 adult females	100.0
	White rats	12 adult males	100.0
	White rats	6 adult females	100.0

LVW/lkv; 2/10/78

BEST DOCUMENT AVAILABLE

Connecticut

Amer. Society for Hort. Sciences 45: 136-140 1944

1685

MB Rodents

Some Trials With Methyl Bromide as a Fumigant for Rodents in Cold Storages

By F. W. Southwick, *University of Connecticut*, and F. B. Schuler, and G. N. Alpaugh, *U. S. Fish and Wildlife Service, Storrs, Conn.*

The annual loss of apples in common and cold storages due to the activities of rats and mice is undoubtedly large. These losses often occur in storages of rodent-proof construction, since rats and particularly the mice, are carried into the storage with the fruit during the harvest season.

Strychnine treated oats, carefully placed about the storage, are recommended as a means of controlling rodents. Baiting methods, however, have not always been effective because growers often have failed to appreciate the important details of baiting, and under certain conditions it is difficult to expose the oats where the rodents will find them. Consequently, the fumigation of storages is worthy of consideration.

When initiating this study it was obvious that a fumigant possessing a low boiling point and good penetrating qualities was necessary if control was to be obtained. Methyl bromide has a boiling point of 40.1 degrees F. This material is so near its boiling point at cold storage temperatures that it evaporates and tends to diffuse very rapidly. It *is also non-inflammable. The fact that it is odorless or practically so* at many of its useful concentrations is an advantage because it cannot directly flavor the fruit. However, the lack of odor makes this material somewhat dangerous to humans who may not suspect its presence at lethal concentrations. Halide detectors are available and can be used as indicators of the presence of methyl bromide.

Sherrard (6) has shown that the minimum lethal dose for wild rats exposed to methyl bromide for four hours at 76 to 79 degrees F *is ⅛ pound per 1,000 cubic feet. In dairy plants, at 70 degrees* F or higher, Searles (5) has readily killed white laboratory rats in five hours, using approximately ⅕ pound per 1,000 cubic feet. Since the temperatures in cold storages are considerably lower than those employed by other investigators, a number of trials were conducted with rodents held at 32 degrees F, it being necessary to determine what concentration, if any, would give satisfactory control of rodents during a fumigation period of from 4 to 5 hours.

Methods and Materials

The white rats and mice employed were obtained from various laboratories at the University of Connecticut and the Connecticut Agricultural Experiment Station at New Haven. These rodents had been maintained on non-deficiency diets. The other rodents were collected in the field. At the end of each trial the animals were sexed. Weights were obtained, immediately after each given trial if the rodents were dead, or as soon as they had succumbed. The weight of the white mice ranged from 6.0 to 29.8 gms, the meadow mice from 22.7 to

45

BEST DOCUMENT AVAILABLE

Reference # 1685

Location University of Connecticut, Storrs, Connecticut

Number of Replications ________ Plot Size ________

Time and Date of Applicatio. ________

~~Soil Texture~~ ________

~~Soil~~ Temperature 32 °F

~~Soil Moisture~~ ________

~~Other Soil Conditions~~ ________

Crop (Variety) ________

Chemical Methyl Bromide (100%) Rate 0.25, 0.5, 1.0, 2.0, 4.0 lbs/1000ft³

Method of Application Probably in evaporating dishe

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4.00	Female	76
Control	Female	Not dead after 4 hours at 32 degrees F
Control	Male	Not dead after 4 hours at 32 degrees F

TABLE II—THE EFFECTIVENESS OF METHYL BROMIDE IN KILLING RODENTS IN A SMALL STORAGE ROOM AT 32 DEGREES F

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		White rats	2	Juvenile	0.0	0.0
		White rats	6	Adult	0.0	0.0

46

TABLE III—THE PER CENT MORTALITY OF RODENTS PLACED IN A COMMERCIAL COLD STORAGE AND SUBJECTED TO VAPORS OF METHYL BROMIDE AT 32 DEGREES F

Treatment (Pounds per 1,000 Cubic Feet)	Species	Number of Rodents	Per Cent Mortality After 5 Hours Treatment
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	White mice	19 adult females	100.0
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LVW/lkv; 2/10/78

BEST DOCUMENT AVAILABLE

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1685

Amer. Society for Hort. Sciences 45: 136-140
1944

MB
Rodents

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47

Rodents

Reference # 1686

Location Massachusetts State College, Amherst, MA

Number of Replications ________ Plot Size ________

Time and Date of Application May 1944, October 1944

~~Soil Texture~~ ________

~~Soil~~ Temperature ________

~~Soil Moisture~~ 34°F

~~Other Soil Conditions~~ ________

Crop (Variety) Apples (McIntosh, Rhode Island Greening, Delicious, Cortland, Baldwin)

Chemical Methyl Bromide Rate 0.125, 0.25, 0.5, 1.0 lbs/1000 ft^3

Method of Application Probably in evaporating dishes

TABLE I—EFFECT ON ANIMALS OF METHYL BROMIDE USED AT THE RATE OF 0.25 POUNDS PER 1000 CUBIC FEET OF STORAGE SPACE

Species	Sex	Age	Weight (Gms)	Hours of Exposure Resulting in Death
Iouse Mouse	Female	Adult	13.0	3
Iouse Mouse	Male	Adult	15.6	3
Iouse Mouse	Female	Adult	20.0	3
Iouse Mouse	Female	Adult	17.6	3
Vhite Rat	Male	Adult	295.7	4
Vhite Rat	Male	Adult	280.7	4
Vhite Rat	Female	Immature	112.0	3
Vhite Rat	Female	Immature	91.0	3
abbit	Female	7 weeks	2 lbs, 11 oz.	5
abbit	Male	7 weeks	2 lbs, 14 oz.	5*

* Paralyzed and died 1 day later.

TABLE II—EFFECT ON ANIMALS OF METHYL BROMIDE USED AT VARIOUS DOSAGES AS SHOWN BELOW

Species	Sex	Age	Weight (Gms)	Effect on Animals
0.125 Pounds per 1,000 Cubic Feet of Storage Space for 6 Hours				
White Rat	Female	Mature	182.0	Paralyzed, died in less than 12 hours
White Rat	Female	Mature	162.8	Death
White Rat	Male	Immature	75.0	Death
White Rat	Male	Immature	71.0	Death
White Rat	Female	Mature	164.1	Paralyzed, died in less than 12 hours
White Rat	Female	Mature	171.0	Paralyzed, died in less than 12 hours
White Rat	Female	Mature	157.3	Paralyzed, died in less than 12 hours
White Rat	Female	Mature	167.0	Paralyzed, died in less than 12 hours
White Rat	Male	Mature	193.4	Paralyzed, died in less than 12 hours
White Rat	Female	Mature	193.4	Paralyzed, died in less than 12 hours
House Mouse	Male	Mature	23.7	Paralyzed, died in less than 12 hours
Guinea Pig	Male	Mature	515.4	Paralyzed, died in less than 12 hours
Guinea Pig	Male	Mature	518.3	Paralyzed, died in 24 hours
0.25 Pounds per 1,000 Cubic Feet of Storage Space for 4 Hours				
House Mouse	Male	Adult	25.0	Death
White Rat	Male	Adult	215.5	Death
White Rat	Female	Adult	199.5	Death
Meadow Mouse	Male	Adult	40.0	Death
Meadow Mouse	Male	Adult	27.5	Death
Meadow Mouse	Female	Juvenile	17.5	Death
Meadow Mouse	Female	Adult	20.5	Death
Meadow Mouse	Male	Juvenile	14.0	Death
0.50 Pounds per 1,000 Cubic Feet of Storage Space for 2 Hours				
Wild Rat	Female	Mature	190.5	Death
Wild Rat	Male	Mature	376.0	Paralyzed, died in 4 hours
White Rat	Female	Immature	80.0	Death
White Rat	Female	Immature	85.0	Paralyzed, died in 4 hours
House Mouse	Male	Mature	25.2	Death
House Mouse	Male	Mature	24.0	Death
Meadow Mouse	Male	Mature	28.0	Paralyzed, died in 5 hours
Meadow Mouse	Female	Mature	15.5	Death
1.0 Pounds per 1,000 Cubic Feet of Storage Space for 1 Hour				
White Rat	Female	Mature	204.0	Paralyzed, died in 1 hour
White Rat	Female	Mature	180.8	Paralyzed, died in 1 hour
White Rat	Female	Mature	207.5	Paralyzed, died in 3 hours
White Rat	Male	Mature	180.7	Paralyzed, died in 3 hours
Meadow Mouse	Male	Mature	27.[illegible]	Paralyzed, died in 3 hours
Meadow Mouse	Female	Mature	24.7	Paralyzed, died in 3 hours
Meadow Mouse	Female	Mature	17.7	Paralyzed, died in 3 hours
House Mouse	Male	Mature	21.3	Death
House Mouse	Male	Mature	24.7	Death
House Mouse	Female	Mature	25.6	Death

LVW/lkv; 2/10/78

Massachusetts

1686

Amer. Society for Hort. Sciences 45: 146-150 pp. 1944 MB Rodents

Methyl Bromide as a Fumigant for Rats and Mice in Apple Cold Storages[1]

By Robert M. Borg, *U. S. Department of the Interior, Fish and Wildlife Service* and Lawrence Southwick, *Massachusetts State College, Amherst, Mass.*

In recent years, rodents (rats and mice) have become pests of considerable economic importance in fruit and vegetable storages in spite of the use of present control measures — poisoning, trapping, and proofing. A search of the literature revealed the possibility of methyl bromide as an effective fumigant to use in fruit storages. Methyl bromide (CH_3Br) is a colorless, practically odorless (resembles that of chloroform), volatile liquid, with a specific gravity of 1.732 at 0 degrees C and a boiling point of 40.1 degrees F. At ordinary temperatures, it is a gas approximately 3.3 times as heavy as air. It is soluble in most common organic solvents but only slightly so in water. It is usually noninflammable. Since it has a low boiling point, it tends to evaporate and diffuse very rapidly. And since it is practically odorless and has a low water solubility, the chance that low concentrations would leave a residual odor or taste on fruit in cold storage would seem to be practically negligible.

Procedure

A small room (734.4 cubic feet) in the apple storage at Massachusetts State College was used. This room is separated from adjacent chambers by heavily insulated walls and contains brine coils for refrigeration. There is one small window near the ceiling in the back wall. This was replaced with heavy brown paper firmly sealed to prevent the escape of gas. An electric fan was set up on the window just inside the paper seal. When it was desired to vent the room of the methyl bromide gas, the paper seal was broken from the outside and the fan was turned on. Another fan near the floor helped to air the room quickly. At the end of 10 minutes venting, no evidence of methyl bromide could be detected by the use of a halide detector.

Only enough boxes were stacked in the room to make it possible to expose the rodents at varying heights in cages containing litter and bedding, used as nests. All animals used in the tests were placed in the room about 1 hour before treatment with methyl bromide. Several varieties of apples were placed in the room for each separate test so that any injury to the exposed fruit might be checked. Using a gas mask, the senior author in each test liberated the desired quantity of the gas in the room. A circulating fan on the floor was turned on at low speed and run continuously to prevent possible stratification of the gas and to provide the most rapid rate of kill.

[1]Contribution No. 544 from the Massachusetts Agricultural Experiment Station.

Mouse - Rodent
Short tailed meadow mice

Reference # 1689

Location Dominion Experiment Station, Summerland, BC

Number of Replications ________ Plot Size ________

Time and Date of Application ________

~~Soil~~ ~~Texture~~ ________

~~Soil~~ Treatment Temperature 32°F

~~Soil~~ ~~Moisture~~ ________

Other ~~Soil Conditions~~ ________

Crop (Variety) Apples

Chemical Methyl Bromide (100%) Rate 1/4, 1/2, 1, 2 lbs/1000ft^3

Method of Application Applied to evaporating dish or floor.

Test in 8 cubic foot chamber

Table 4. Time-concentration rates for killing mice in cold storages with methyl bromide.

32°F

Date of fumigation	CH_3Br per 1000 cu. ft.	Exposure	Time to kill mice	Injury to apples
	pounds	hours	hours	
Nov. 26	1/4	4 1/2	3	0
Nov. 29	1/4	4	3	0
Nov. 29	1/2	4	2 1/6	0
March 8	1	4	No mice	0
March 20	2	4	No mice	0

17,000 cubic foot fumigation

A small commercial storage room 17,000 cubic feet capacity was fumigated December 5 using ¼ pound of methyl bromide per 1000 cubic feet of free air space and allowing 10 per cent for leakage. Of the 14 mice placed at various points throughout the room, 12 were dead at the end of 4 hours and the other 2 died within 4 hours of removal to fresh air. No injury to the apples resulted. The Halide leak detector showed considerable leakage around doors and ports and a reduced concentration in the storage towards the end of the fumigation period.

These results indicate that ¼ pound of methyl bromide per 1000 cubic feet kills mice within 4 hours without damage to apples in cold storage.

LVW/lkv; 2/10/78

British Columbia

Amer. Society for Hort. Science 60: 265-271 (1689)

MB Rodents

Mouse Control in Fruit Cold Storages by Means of Carbon Monoxide and Methyl Bromide Fumigation[1]

By S. W. Porritt, D. V. Fisher, and E. D. Edge, *Dominion Experimental Station, Summerland, B. C.*

Heavy infestations of mice in orchards of the Okanagan Valley during the 1948 and 1949 seasons resulted in large numbers entering storages in loose boxes of fruit, thereby causing serious economic losses to many packing houses. Since neither poison bait nor cats gave effective control, fumigation was considered. Fumigation experiments using carbon monoxide and methyl bromide are reported in this paper.

Review of Literature

The lethal properties of carbon monoxide are well known, but no exact information as to its possible use for exterminating mice in fruit storages was available. Verbal reports from the State of Washington indicated that carbon monoxide in exhaust gases from gasoline engines had been used successfully as a storage fumigant for mice.

Methyl bromide, on the other hand, is used extensively for fumigation of food warehouses, ships and railway cars containing nonperishable foodstuffs. Phillips (10, 11) and Kenworthy (6, 7) report that fumigation of fresh fruits with methyl bromide for control of Japanese beetle and codling moth, at concentrations of 2 to 3 pounds per 1000 cubic feet at 75 degrees F, resulted in varying amounts of injury to the fruit. Phillips et al (10), using methyl bromide at the rate of 2.5 pounds per 1000 cubic feet on apples at a core temperature of 75–78 degrees F, produced some internal and external injury, but when fruit was harvested at the correct maturity and fumigation delayed until 6 weeks after picking, injury was negligible.

Kenworthy (6, 7) fumigated iced cars of apples with 2 to 3 pounds of methyl bromide per 1000 cubic feet, within a temperature range of 50 to 75 degrees F. Severity of injury increased with higher temperatures and varied with different varieties.

Southwick et al (12, 13, 14) and Borg et al (1) made specific application of methyl bromide to fruit cold storages for control of rodents. In storages at 32 to 36 degrees F, methyl bromide, at a concentration of ¼ pound per 1000 cubic feet of free air space for 4 to 5 hours, gave a complete kill of rats and mice with no injurious effects to fruit.

Southwick (12, 13) observed that methyl bromide stimulated respiration and ripening of pre-climacteric fruit, but had no effect on fruit that had begun the climacteric rise. Claypool (2) reported accelerated ripening on Bartlett pears with concentrations of 2 or more pounds of methyl bromide per 1000 cubic feet with no actual physical harm to the fruit, but in general a deterioration in subsequent eating quality. Knott and Claypool (8) found that methyl bromide stimulated certain metabolic processes of "mature green" tomatoes.

[1]Contribution No. 791 Division of Horticulture, Experimental Farms Service, Dominion Department of Agriculture. Received for publication June 21, 1952.

Mexico

MB Ticks (468)

PRELIMINARY TESTS WITH METHYL BROMIDE AND DICHLORVOS AS FUMIGANTS FOR *BOOPHILUS* SPP. TICKS AT QUARANTINE STATIONS

ARS-S-102
March 1976

AGRICULTURAL RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

CONTENTS

TABLES

Mexico

468

MB ticks

PRELIMINARY TESTS WITH METHYL BROMIDE AND DICHLORVOS AS FUMIGANTS FOR *BOOPHILUS* SPP. TICKS AT QUARANTINE STATIONS

By W. J. Gladney[1]

ABSTRACT

Fumigating engorged female ticks (*Boophilus annulatus* and *Boophilus microplus*) with methyl bromide gas for 15 minutes in metal drums prevented the ticks from laying eggs (caused 100 percent female mortality). The effectiveness of dichlorvos strips (20 percent active ingredient) depended on temperature and length of exposure: at 1° to 6° C, tick control (an estimate based on the decrease in the reproduction of treated ticks when compared to the reproduction of untreated ticks) ranged from 16 percent after 1 hour of fumigation to 64 percent after 24 hours; at 29° to 34° C, control ranged from 36 percent after 1 hour of exposure to 81 percent after 24 hours. Technical dichlorvos afforded consistently poor control (0 to 25 percent) at all temperatures and exposures tested. In limited tests, immersion of engorged female *B. annulatus* in saturated NaCl solutions also provided consistently poor control (0 percent after 5 minutes to 27 percent after 1.5 hours).

INTRODUCTION

The importation into the United States of hunting trophies from Mexico poses a problem for Federal animal health officials. Occasionally, Animal Plant and Health Inspection Service (APHIS) personnel at border inspection stations find that such items as deer hides and heads are infested by ticks. Because APHIS, an agency of the U.S. Department of Agriculture (USDA), is charged with enforcing quarantine regulations to prevent importation of *Boophilus* spp. ticks into the United States, inspection personnel need a suitable and reliable technique for killing all *Boophilus* spp. females.

At present, APHIS has no dependable method for killing *Boophilus* spp. ticks on trophies. Sometimes trophies are packed inside plastic bags with a saturated NaCl solution to kill ticks, but the effectiveness of this treatment is unknown. Many ports of entry along the United States-Mexican border are small facilities with limited personnel who are not experienced in handling control chemicals. Also, rapid treatment of trophies is necessary so that hunters returning to the States will be detained for as little time as possible. Therefore, APHIS personnel need a simple, safe, rapid, and effective technique for killing all *Boophilus* spp. females that may be attached to trophies.

APHIS requested that the Agricultural Research Service (ARS) do limited experimental testing to determine the effectiveness of dichlorvos and methyl bromide (MeBr) in the fumigating and killing of female *Boophilus* spp. ticks. Little information is available regarding the efficacy of fumigants against ticks, and no

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information is available on the efficacy of dichlorvos vapors on engorged female *Boophilus* spp. ticks. Barnett and Parsons[2] fumigated bales of hay infested with several species of ticks with MeBr and obtained variable results. Roth[3] obtained 100 percent control of unengorged adult *Rhipicephalus sanguineus* (Latreille) (brown dog tick) with MeBr in fumigation drums.

Reported here are results of preliminary tests with dichlorvos and MeBr against engorged females of *Boophilus annulatus* (Say) and *B. microplus* (Canestrini). All tests were conducted at a sublaboratory of the U.S. Livestock Insects Laboratory (ARS) at Nuevo Laredo, Tamaulipas, Mexico, during 1973.

MATERIALS AND METHODS

From 1964 until 1974, we maintained colonies of *B. annulatus* and *B. microplus* on cattle at Nuevo Laredo for use in spray or dipping tests with tick-infested cattle, in laboratory dipping tests, and in basic biological studies. Drummond et al.[4] have described in detail the rearing procedures and handling methods used with the ticks. Engorged female ticks available from infestations established for the usual insecticidal tests were used in the fumigation tests reported here.

Test 1

In early January of 1973, fresh hides of white-tailed deer, *Odocoileus virginianus* (Boddaert), were available from a local slaughterhouse. We obtained three hides weighing between 1.71 and 2.12 kilograms from the slaughterhouse.

Groups of 10 female *B. annulatus* were weighed and placed inside specially constructed screen wire cages of 1- by 1-millimeter mesh copper screen. The cages were 9.5 centimeters long and 2.5 centimeters in diameter. After the females were placed inside, the cages were stoppered with a plastic No. 12 Caplug. A total of 18 cages were used, with 10 ticks in each cage.

Three 208-liter (55-gallon) drums were used as fumigation chambers. The outer rims of the drum lids were lined with weather stripping to create an airtight seal when the lids were secured on the drums with metal rim straps.

A special false bottom was constructed of a No. 9 flattened expanded metal (hole size, 1.9 by 3.8 centimeters) to go inside the first drum. The false bottom was 54.6 centimeters in diameter; it fit just inside the 57.1-centimeter-diameter drum and was supported by three 20.3-centimeter-high legs which rested on the bottom of the drum. This circular metal grate supported a deer hide above a 1-liter beaker containing technical dichlorvos which rested on the bottom of the drum.

A metal hook was soldered to the center of the lid of the second drum so that dichlorvos strips[5] could be suspended by wires from the hook. No special modifications were made on the third drum, which served as a control.

In the first drum, 45 grams of technical dichlorvos was poured in the 1-liter beaker; in the second drum, two 20 percent dichlorvos strips (total weight, 225 grams) were suspended from the metal hook; the third drum received no treatment.

One deer hide was placed in each drum, and three cages of engorged females were folded in the center of each hide so that the cages were completely covered with the hairy side of the hide. Three other cages were placed directly on top of the flesh side of each hide Thus, a total of six cages were placed in each of the three drums. Timing of the test began when the metal lids were secured to the tops of the drums.

Drums were opened at the end of 1, 4, and 24 hours of exposure, and one cage was removed from both the top and the middle of each hide after each exposure period. All fumigation tests were conducted in open-sided stalls with a wooden roof so that the drums were exposed to ambient temperatures that ranged from 1° to 6° C at normal atmospheric pressure.

Immediately after removal from the drums, the 10 females in each cage were transferred to a labeled 8-dram glass vial and placed in a constant-temperature chamber (27° C and about 85

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[2] Barnett, S. F., and Parsons, B. T. 1963. The control of ticks on fodder and bedding using methyl bromide. Vet. Rec. 75: 1213–1215.

[3] Roth, H. 1973. Fumigants for quarantine control of the adult brown dog tick: Laboratory studies. J. Econ. Entomol. 66: 1283–1286.

[4] Drummond, R. O., Graham, O. H., Ernst, S. E., and Trevino, J. L. 1967. Evaluation of insecticides for the control of *Boophilus annulatus* (Say) and *B. microplus* (Canestrini) [Acarina: Ixodidae] on cattle. Proc. 2d Int. Congr. Acarol., pp. 493–498.

[5] No-Pest Strip Insecticide, Shell Chemical Co., San Ramon, Calif. 94583 (active ingredients: 18 percent dichlorvos, 2 percent related compounds; 80 percent inert ingredients).

percent relative humidity). After the females completed oviposition, their eggs were removed, weighed, and returned to the chamber. After hatching of eggs was complete, the percentage of egg hatch was estimated.

The estimated reproduction (ER) was calculated for each group of females by the formula

$$\frac{\text{g eggs}}{\text{g} \ \female} \times \text{hatch} \times 20{,}000 = \text{ER}$$

where g eggs = weight of eggs, in grams,
g ♀ = weight of females, in grams,
% hatch = percentage of eggs laid that hatch,
and 20,000 = a constant, the number of eggs in a 1-gram mass.

Percentage of control for each treatment was then calculated by the formula

$$\frac{\text{untreated ER} - \text{treated ER}}{\text{untreated ER}} \times 100 = \% \text{ control}.$$

Test 2

In mid-June of 1973, a second test was conducted in which dichlorvos strips, technical dichlorvos, and MeBr gas were evaluated. Fresh deer hides were not available at that time of year so the test was conducted in a manner similar to that of test 1 except that cages of females were placed inside the drums without wrapping them in deer hide. Also, an additional exposure time of 2 hours was evaluated.

Dichlorvos, both in 20 percent strips and as a technical liquid, was tested against *B. microplus* females by placing the two formulations inside the fumigation drums as in test 1. The number of replications (10 females per cage) per treatment and exposure time ranged from 2 to 6. Only one replication per exposure time was run for the untreated controls.

A soil fumigant contained in cans as a liquid under pressure was the source of MeBr.[6] A special hose with a metal adapter was affixed to each can, puncturing the can. A valve at the junction of the adapter and the can kept the fumigant from being released as a gas. The hose was then inserted into a fumigation drum through a small slit between the lid and upper rim of the drum and the valve was opened, releasing the gas into the drum for either 15 seconds or 1 minute.

Cages containing the female ticks were placed inside the drums immediately before the gas was released and were removed from the drums immediately after their exposure time was complete. Protective equipment (respiratory mask, eye goggles, and rubber gloves) was worn by the investigator while the gas was introduced into the drums and while females were being removed from the drums. With *B. microplus*, six cages of females were exposed to the MeBr gas for 15 minutes, and six additional cages were exposed for 1 hour. With *B. annulatus*, four cages were exposed for 1 hour. Temperatures during test 2 ranged from 29° to 34° C. Females were maintained and ER for each group was computed as in test 1.

Test 3

In this brief test, saturated NaCl solution was evaluated for its effectiveness in the control of reproduction of female *B. annulatus*.

NaCl crystals were stirred into 100 milliliters of water until no more of the salt would go into solution and a residue of the crystals remained in the bottom of 135-milliliter ice cream cups. Ten females were placed in each of four different cups and exposed to the solutions for 30 seconds, 5 minutes, 1.5 hours, or 2 hours. Ten control females were placed in untreated water for 2 hours. Females were allowed to air-dry by confining them on paper towels before they were placed in vials. The vials were placed in constant-temperature chambers as in test 1, and ER was computed for the females as in tests 1 and 2.

RESULTS

Test 1

Table 1 shows that dichlorvos vapors from the strips provided a higher level of control of ER than did the technical liquid. The highest level of control was obtained with ticks located on top of the deer hide exposed to the strips for 24 hours. Level of control by strips was greatly reduced at exposure times of less than 24 hours and was less for ticks folded inside the deer hides than for ticks on top of the hide. Control provided by technical liquid was extremely low for all exposure times and for both cage locations. Low ambient temperatures that prevailed during test 1 probably accounted for the low level of

[6] Pestmaster Soil Fumigant-1, Michigan Chemical Corp., Chicago, Ill. (active ingredients 98 percent MeBr, 2 percent chloropicrin).

3

TABLE 1.—*Reproduction of engorged female* Boophilus annulatus *after exposure to technical dichlorvos or dichlorvos strips in fumigation drums*

Formulation and cage position	Exposure (hours)	Weight of 10 ♀ (grams)	Weight of total egg masses (grams)	Hatch (pct of eggs laid)	Reproduction	
					ER[1]	Pct of control
Strip:						
On top of deer hide	1	3.06	1.635	85	9,083	16
Do	4	3.58	1.994	90	10,026	11
Do	24	3.12	.632	95	3,849	64
Covered by deer hide	1	3.30	1.810	90	9,873	12
Do	4	3.36	1.989	95	11,247	0
Do	24	3.36	1.789	85	9,052	21
Technical:						
On top of deer hide	1	3.49	2.027	90	10,454	4
Do	4	3.26	1.876	95	10,934	3
Do	24	3.51	1.904	97	10,524	2
Covered by deer hide	1	3.27	1.748	95	10,157	9
Do	4	3.44	2.005	90	10,491	0
Do	24	3.25	1.632	95	9,541	17
Control:						
On top of deer hide	1	3.19	1.819	95	10,834	..
Do	4	3.28	1.913	97	11,315	..
Do	24	3.41	1.882	97	10,707	..
Covered by deer hide	1	3.61	2.130	95	11,211	..
Do	4	3.19	1.827	80	9,164	..
Do	24	3.39	2.046	95	11,467	..

[1] ER = Estimated reproduction.

control observed since the vaporization and insecticidal activity of dichlorvos are reduced at lower temperatures.

Test 2

Table 2 shows a direct exposure time-activity relationship for dichlorvos strips; the longer the exposure time, the greater the percentage of control. A higher level of control provided by strips was observed in test 2 than in test 1, apparently due to the higher ambient temperatures that prevailed during test 2. Also, as in test 1, technical dichlorvos provided a lower level of control than did the dichlorvos from strips. A fumigant containing 98 percent MeBr was 100 percent effective at various exposure times against both species of female *Boophilus*.

Test 3

The data in table 3 show the relative ineffectiveness of saturated NaCl solutions for control of female *B. annulatus*. Exposure times of 5 minutes or less had virtually no effect on the reproduction of this species, while exposure times of 1.5 to 2 hours provided very slight control of ER.

CONCLUSIONS

MeBr fumigation was by far the most satisfactory treatment tested from the standpoint of both minimum required exposure time and effectiveness of the chemical in the control of ticks. Fumigation with MeBr requires the use of safety equipment such as gas masks, eye goggles, and rubber gloves by personnel conducting the operation. Fumigation with this gas should be done outdoors.

Technical dichlorvos in drums would not be satisfactory for the fumigation of hunting trophies at ambient temperatures because of the low level of control observed with this formula-

TABLE 2.—*Reproduction of engorged female* Boophilus *spp. ticks after exposure to dichlorvos strips, technical dichlorvos, or MeBr gas in fumigation drums*

Treatment, species, and formulation	Replications	Exposure (hours)	Average total ♀ weight per replication (grams)	Weight of total egg masses, average per replication (grams)	Average hatch (pct of eggs laid)	Reproduction	
						Average ER[1]	Average pct of control[2]
Dichlorvos, *B. microplus*:							
Strip	6	1	3.15	1.164	79	5,995	36
Do	4	2	3.03	.964	88	5,501	47
Do	2	4	3.22	.642	88	3,456	66
Do	2	24	3.08	.441	58	1,616	81
Technical	6	1	3.04	1.516	95	9,455	0
Do	4	2	2.86	1.529	90	9,620	6
Do	2	4	3.11	1.218	98	7,686	25
Do	2	24	3.17	1.574	95	9,443	0
Control	1	1	3.05	1.504	95	9,369	..
Do	1	2	2.96	1.552	98	10,277	..
Do	1	4	3.17	1.655	98	10,233	..
Do	1	24	3.23	1.391	98	8,441	..
MeBr, *B. microplus*:							
Gas[3]	6	1	3.01	0	0	0	100
Do[4]	6	.25	3.13	0	0	0	100
Control	1	1	3.00	1.786	95	11,311	..
Do	1	.25	3.35	1.612	95	9,143	..
MeBr, *B. annulatus*:							
Gas[3]	4	1	2.96	0	0	0	100
Control	1	1	2.79	1.372	80	7,868	..

[1] Estimated reproduction.
[2] Based on average treated ER and untreated ER.
[3] 1 minute elapsed while gas traveled from the can into the drum.
[4] 0.25 minute elapsed while gas traveled from the can into the drum.

TABLE 3.—*Reproduction of engorged female* Boophilus annulatus *dipped in saturated NaCl solution*

Time in solution	Weight of 10 ♀ (grams)	Died without ovipositing	Weight of total egg masses (grams)	Hatch (pct of eggs laid)	Reproduction	
					ER[1]	Pct of control
30 seconds	2.77	2	1.372	95	9,411	3
5 minutes	2.87	1	1.507	95	9,977	0
1.5 hours	3.49	1	1.659	75	7,130	27
2 hours	3.23	3	1.346	95	7,918	19
2 hours[2]	3.17	0	1.714	90	9,733	..

[1] Estimated reproduction.
[2] Controls in untreated water.

tion in both tests 1 and 2. Dichlorvos strips may be used to achieve a relatively high level of control if ambient temperatures are moderately high, exposure time can be long (>24 hours), and hides are placed so that the outer skin is fully exposed to the vapors.

Packing hides in a saturated NaCl solution would not be a satisfactory treatment for control of *Boophilus* females.

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